Total Maximum Daily Load Development for Linville Creek: Bacteria and General Standard (Benthic) Impairments

Submitted by:

Virginia Department of Environmental Quality
Virginia Department of Conservation and Recreation

Prepared by:

Department of Biological Systems Engineering, Virginia Tech

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Project Personnel

Virginia Tech, Department of Biological Systems Engineering

Brian Benham, Assistant Professor and Extension Specialist
Kevin Brannan, Research Associate
Theo Dillaha, III., Professor
Saied Mostaghimi, Professor
Jeff Wynn, Research Associate
Gene Yagow, Research Scientist
Rebecca Zeckoski, Research Associate

Virginia Department of Environmental Quality

Sandra Mueller, Project Coordinator
Jutta Schneider
Bill Van Wart
Gary Flory
Larry Hough

Virginia Department of Conservation and Recreation (VADCR)

Mike Shelor, Project Coordinator
Tamara Keeler
Mark Hollberg
Crawford Patterson

For additional information, please contact:

Virginia Department of Environmental Quality (VADEQ)

Water Quality Assessment Office, Richmond: Sandra Mueller, (804) 698-4324
Valley Regional Office, Harrisonburg: Gary Flory, (540) 574-7840

BSE Department: Saied Mostaghimi, Project Director, (540) 231-7605
Email: smostagh@vt.edu

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CHAPTER 1: EXECUTIVE SUMMARY

1.1. Background

Located in Rockingham County, Virginia, the Linville Creek watershed (VAV-B46R, 29,647 acres) is bounded by Harrisonburg to the south and Broadway to the north. Linville Creek is a tributary of the North Fork of the Shenandoah River (USGS Hydrologic Unit Code 02070006), which in turn, is a tributary of the Potomac River. The Potomac River discharges into the Chesapeake Bay.

1.2. Bacteria Impairment

1.2.1. Background

Water quality samples collected in Linville Creek over a period of 8 ½ years (September 1993 – April 2002) indicated that 34% of the samples violated the instantaneous water quality standard for fecal coliform. The instantaneous standard specifies that fecal coliform concentration in the stream water shall not exceed 1,000 colony forming units (cfu) per 100 mL. Due to the frequency of water quality violations, Linville Creek has been placed on Virginia's 1998 303(d) list of impaired water bodies for fecal coliform. It has been assessed as not supporting the Clean Water Act's Swimming Use Support Goal for the 1998 305(b) report. The impairment starts at the headwaters and continues downstream to its confluence with the North Fork of the Shenandoah River, for a total of 13.55 stream miles.

In order to remedy the water quality impairment pertaining to fecal coliform, a Total Maximum Daily Load (TMDL) has been developed, taking into account all sources of bacteria and a margin of safety (MOS). The TMDL was developed for the new water quality standard for bacteria, which states that the calendar-month geometric mean concentration of *E. coli* shall not exceed 126 cfu/100 mL, and that no single sample can exceed a concentration of 235 cfu/100mL. A glossary of terms used in the development of this TMDL is listed in Appendix A.

1.2.2. Sources of Bacteria

There is one significant point source and 28 smaller sources permitted to discharge bacteria in the Linville Creek watershed; however, the majority of the bacteria load originates from nonpoint sources. The nonpoint sources of bacteria are mainly agricultural and include land-applied animal waste and manure deposited on pastures by livestock. A significant bacteria load comes from cattle and wildlife directly depositing in streams. Wildlife also contribute to bacteria loadings on all land uses, in accordance with the habitat range for each species. Non-agricultural nonpoint sources of bacteria loadings include failing septic systems and pet waste. The amounts of bacteria produced in different locations (e.g., confinement, pasture, forest) were estimated on a monthly basis to account for seasonal variability in wildlife habitat and livestock production and practices. Livestock management and production factors, such as the fraction of time cattle spend in confinement, pastures, or streams; the amount of manure storage; and spreading schedules for manure application, were considered on a monthly basis.

1.2.3. Modeling

The Hydrologic Simulation Program – FORTRAN (HSPF) was used to simulate the fate and transport of fecal coliform bacteria in the Linville Creek watershed. To identify localized sources of fecal coliform within the Linville Creek watershed, the watershed was divided into eleven sub-watersheds, based on homogeneity of land use.

The hydrology component of HSPF was calibrated and validated for Linville Creek. The HSPF model was calibrated for Linville Creek using data from a 5.3-year period. The calibration period covered a wide range of hydrologic conditions, including low- and high-flow conditions and seasonal variations. The calibrated HSPF data set was validated on a separate period of record for Linville Creek (8.75 years). The calibrated HSPF model adequately simulated the hydrology of the Linville Creek watershed.

The water quality component of the HSPF model was calibrated using eight years (November 1993 – September 2001) of fecal coliform data collected in the watershed. Inputs to the model included fecal coliform loadings on land and in the stream and simulated flow data. A comparison of simulated and observed fecal coliform loadings in the stream indicated that the model adequately simulated the fate of fecal coliform in the watershed.

1.2.4. Margin of Safety

A margin of safety (MOS) is included to account for any uncertainty in the TMDL development process. There are several different ways that the MOS could be incorporated into the TMDL (USEPA, 1991). For the Linville Creek TMDL, the MOS was implicitly incorporated into the TMDL by conservatively estimating several factors affecting bacteria loadings, such as animal numbers, production rates, and contributions to streams.

1.2.5. Existing Conditions

Based on amounts of fecal coliform produced in different locations, monthly fecal coliform loadings to different land use categories were calculated for each sub-watershed for input into the model. Fecal coliform content of stored waste was adjusted to account for die-off during storage prior to land application. Similarly, fecal coliform die-off on land was taken into account, as was the reduction in fecal coliform available for surface wash-off due to incorporation following waste application on cropland. Direct seasonal fecal coliform loadings to streams by cattle were calculated for pastures adjacent to streams. Fecal coliform loadings to streams and land by wildlife were estimated for several species. Fecal coliform loadings to land from failing septic systems were estimated based on number and age of houses. Fecal coliform contribution from pet waste was also considered.

Contributions from various sources were represented in HSPF to establish the existing conditions for the representative period of 8 years (November 1993 – September 2001). The visual assessment of the simulated and actual values indicated a good agreement between the two. Forty-five percent of the fecal coliform in the mean daily fecal coliform concentration comes from cattle directly depositing in the stream, 31% from upland areas due to runoff, 19% comes from wildlife directly depositing in the stream, and the remaining 5% is accounted for by straight pipes and runoff from impervious areas. Observed and simulated fecal coliform concentrations exceeded the calendar-month geometric mean water quality standard more frequently during low flow periods and the summer. During the summer when stream flow was lower, cattle spent more time in streams, and thereby, increased direct fecal coliform deposition to streams when water for dilution was least available.

1.2.6. Allocation Scenarios

As previously mentioned, Virginia has moved to an *E. coli* standard to measure the potential presence of pathogens in the water. As per the guidance of the Virginia Department of Environmental Quality (VADEQ), the modeling of scenarios was conducted using fecal coliform inputs to the HSPF model, and then a translator equation was used to convert the fecal coliform output to *E. coli*.

After calibrating to the existing water quality conditions, different scenarios were evaluated to identify implementable scenarios that meet both the calendar-month geometric mean *E. coli* criterion (126 cfu/100 mL) and the single sample maximum *E. coli* criterion (235 cfu/100 mL) with zero violations. The scenarios are presented in Table 1.1.

Table 1.1. Allocation scenarios for Linville Creek watershed.

Scenario Number	% Violation of *E. coli* standard		Required Fecal Coliform Loading Reductions to Meet the *E coli* Standards,%						
	Geomean	Single Sample	Cattle DD	Cropland	Pasture	Loafing Lot	Wildlife DD	Straight Pipes	All Residential PLS
01	3%	9%	99	70	70	95	90	100	50
02	0%	2%	99.9	75	75	99	95	100	75
03	0%	0%	99.9	97	97	99.9	99.9	100	97
04	0%	0%	99.9	97	97	99.9	95	100	97
05	0%	1%	99.5	95	95	99.5	97	99.5	99.5
06	0%	0%	99.5	97	97	99.5	97	99.5	97
07	0%	0%	100	96	96	100	95	100	99

In scenario 01, straight-pipes were eliminated and high reductions (at least 90%) were made in direct deposits by cattle and wildlife to streams, along with large reductions from land surface loads (cropland, pasture, loafing lots, and residential), yet there were still violations of both the calendar-month geometric mean (3%) and single sample (9%) *E. coli* standards (Table 1.1). The same was true for scenarios 02 and 05. Scenarios 03, 04, 06, and 07 all met the calendar-month and single sample *E. coli* standards. Scenario 07 was selected as the TMDL allocation because this scenario had slightly lower reductions required for cropland, pasture, residential areas, and wildlife direct deposit compared to the other scenarios that met the *E. coli* standards.

The required load reductions for the TMDL allocation for wet weather nonpoint sources are listed in Table 1.2 and direct nonpoint sources in Table 1.3. The calendar-month geometric mean fecal coliform concentrations resulting from Scenario 07, as well as the existing conditions, are presented graphically in Figure 1.1.

Table 1.2. Annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario (Scenario 07).

Land use Category	Existing Conditions		Allocation Scenario	
	Existing conditions load (× 10^{12} cfu)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (× 10^{12} cfu)	Percent reduction from existing load
Cropland	4.31	0.01%	0.17	96%
Pasture	54,654	94.47%	2,186	96%
Residential[a]	932.2	1.61%	9.3	99%
Loafing Lot	2,251.7	3.89%	0	100%
Forest	12.8	0.02%	12.8	0%
Total	57,885	100%	2,208.4	96%

[a] Includes loads applied to both High and Low Density Residential and Farmstead

Table 1.3. Annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario (Scenario 07).

Source	Existing Condition		Allocation Scenario	
	Existing conditions load (× 10^{12} cfu)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (× 10^{12} cfu)	Percent reduction
Cattle in streams	98.5	88.58%	0	100%
Straight-Pipes	12.0	10.79%	0	100%
Wildlife in Streams	0.7	0.63%	0.035	95%
Total	111.2	100%	0.035	100%

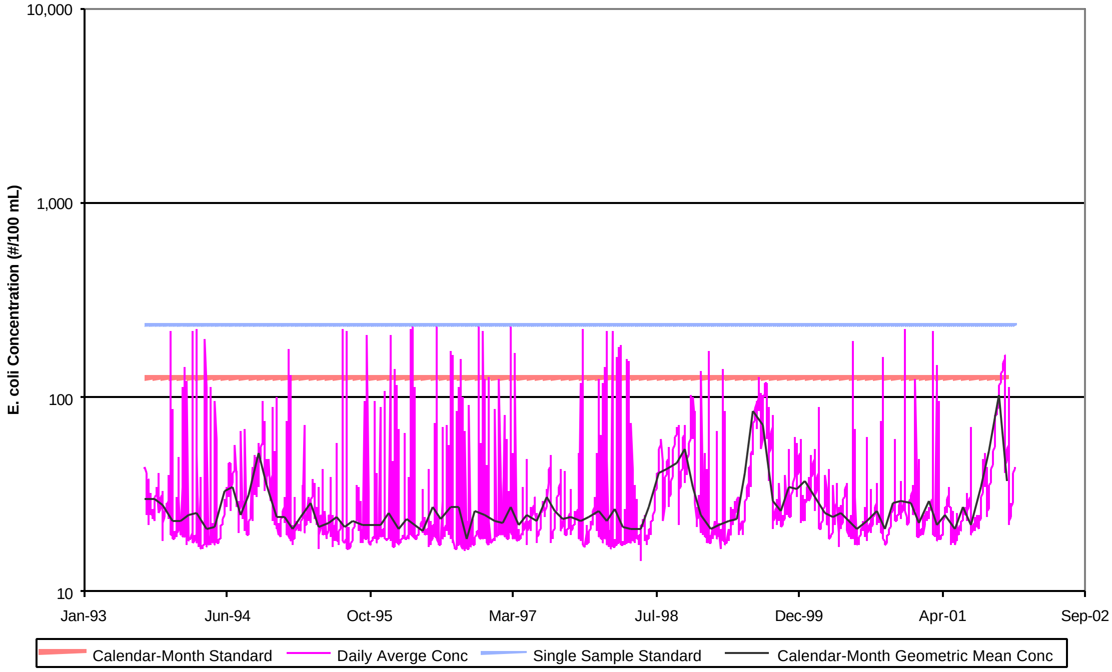


Figure 1.1. Successful *E. coli* TMDL allocation, 126 cfu/100mL geometric mean goal, and 235 cfu/100mL single sample goal for Linville Creek (Scenario 07, Table 1.1).

For the selected scenario (Scenario 07), load allocations were calculated using the following equation.

$$TMDL = SWLA + SLA + MOS \qquad [1.1]$$

where,

WLA = wasteload allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety, implicit.

There is one significant permitted point source of bacteria in the Linville Creek watershed and 33 smaller point sources that are discharging at or below their permit requirements; therefore, the proposed scenario requires load reductions only for nonpoint sources of fecal coliform. The TMDL load was determined as the average annual *E. coli* load at the watershed outlet for the chosen allocation scenario. In Table 1.4 below, the WLA was obtained by summing the products of each permitted point source's *E. coli* discharge concentration and allowable annual discharge. The LA is then determined as the TMDL – WLA.

Table 1.4. Average annual *E. coli* loadings (cfu/year) at the watershed outlet used for the Linville Creek bacteria TMDL.

Parameter	SWLA	SLA	MOS	TMDL
E. coli	11.0×10^{10} *(VA0085588 = $5.22*10^{10}$ SSFH WLA = $5.74*10^{10}$)*	$2{,}106.8 \times 10^{10}$	NA	$2{,}117.8 \times 10^{10}$

NA – Not Applicable because MOS was implicit

The proposed scenario requires a 96% to 100% reduction in fecal coliform loads all land uses except forest and a 95% reduction from wildlife direct deposits to streams to meet the *E. coli* standard. Further, complete exclusion of cattle from streams and elimination of discharge from direct pipes to the stream are required to meet the TMDL goal.

1.2.7. Phase 1 Implementation

An alternative scenario was evaluated to establish a first phase for the implementation of the TMDL. The implementation of such a transitional scenario, or Phase 1 implementation, will allow for an evaluation of the effectiveness of management practices and accuracy of model assumptions through data collection. Phase 1 implementation was developed for a maximum of 10% violation rate of the single sample *E.coli* water quality standard (235 cfu/100 mL), based on daily average of the simulated concentrations. Phase 1 implementation requires a 99% reduction in direct loading by cattle in-stream and elimination of direct discharge by direct pipes. Also, a 70% reduction in loadings from the cropland and pasture upland areas is required. Reductions of 95% and 50% are needed for loads to loafing lots and residential areas, respectively. No reduction in loads from wildlife directly to the stream is required.

1.3. Benthic Impairment

1.3.1. Background

Two or more “moderately impaired” benthic ratings during the 5-yr assessment period used for the 1998 303(d) water quality assessment resulted in the Linville Creek watershed being assessed as not supporting of the Aquatic Life designated use on the same stream segment (13.55 miles) as the fecal coliform impairment. VADEQ listed nonpoint source agricultural pollution as the probable cause of the benthic impairment (VADEQ, 1998).

1.3.2. Benthic Stressor Analysis

TMDLs must be developed for a specific pollutant. Since a benthic impairment is based on a biological inventory, rather than on physical and chemical water quality parameters, the pollutant is not implicitly identified in the assessment, as it is with physical and chemical parameters. The process outlined in the United States Environmental Protection Agency’s (USEPA)

Stressor Identification Guidance Document (USEPA, 2000) was used to identify the critical stressor for Linville Creek.

Sediment was identified as the target pollutant on which the benthic TMDL for Linville Creek will be based. The evidence supporting sediment as the primary stressor came from several sources. Many of the scores for one of the benthic metrics (%haptobenthos) indicated poor habitat for functional groups requiring a coarse, clean sediment substrate. Linville Creek also received repeated low habitat scores for bank stability, substrate availability, bank vegetation, riparian vegetation, and embeddedness. Additionally, there was observed damage to stream banks from livestock trampling. Taken together, these observations from various points of view support the case for sediment as the most likely stressor on the benthic community.

1.3.3. The Reference Watershed Approach

Because Virginia has no numeric in-stream criteria for sediment, a "reference watershed" approach was used to set allowable loading rates in the impaired watershed.

The reference watershed approach pairs two watersheds: one whose streams are supportive of their designated uses, and one whose streams are impaired. This approach is based on the assumption that reduction of the stressor loads in the impaired watershed to the level of the loads in the reference watershed will result in elimination of the benthic impairment.

The reference watershed approach involves assessment of the impaired reach and its watershed, identification of potential causes of impairment through a benthic stressor analysis, selection of an appropriate reference watershed, model parameterization of the reference and impaired watersheds, definition of the TMDL endpoint using modeled output from the reference watershed, and development of alternative TMDL reduction (allocation) scenarios.

The Upper Opequon Creek watershed was selected as the reference watershed for Linville Creek. Land use distribution was considered the most important characteristic considered in this comparison, and the Upper Opequon is the only monitored, non-impaired watershed considered that has a significant urban component, while still comprised predominantly of agricultural land uses. The Upper Opequon watershed is located in the same Level III ecoregion as Linville Creek and the two watersheds share the same major Level IV ecoregion.

1.3.4. Modeling

The sediment TMDL for the Linville Creek watershed was developed using a reference watershed approach, with the Upper Opequon Creek watershed as the reference. The GWLF model, originally developed for use in ungaged watersheds (Haith *et al*., 1992), was used to model both watersheds. However, the BasinSim adaptation of the model (Dai *et al*., 2000) recommends hydrologic calibration of the model, and preliminary calibrated model results for the gaged Linville Creek watershed showed an 18% reduction in the percent error between simulated and observed monthly runoff. Because observed daily flow data were available at both Linville Creek and its reference watershed, hydrologic calibration was performed on both watersheds. To ensure comparability between the target and its reference watershed, GWLF parameters for both watersheds were calibrated in a consistent manner. The GWLF model of each watershed was calibrated for hydrology and then run for existing conditions over a 10-yr period from January 1988 to December 1997. The sediment load from the reference watershed was used to define the target sediment TMDL load for the impaired Linville Creek watershed. Since the watersheds varied slightly in total area, sediment load comparisons were based on a watershed unit area load (t/ha) basis, and were calculated as the 10-yr average annual unit load (t/ha-yr), where t = metric tons (2,204.6 lbs), and ha = hectares (2.471 acres).

1.3.5. Sources of Sediment

In-stream sediment in the watershed is generated by surface runoff from both pervious and imperious areas, by channel erosion, and from permitted discharges.

Pervious area sediment loads were modeled explicitly in the GWLF model using sediment detachment, a modified USLE erosion algorithm, and a sediment delivery ratio to calculate edge-of-stream (EOS) loads and were reported on a monthly basis by landuse. Impervious area sediment loads were modeled explicitly in GWLF using an exponential buildup-washoff algorithm.

Channel erosion was modeled explicitly within GWLF using the algorithms included in the AVGWLF adaptation of the GWLF model (Evans *et al.*, 2001). In these equations, channel erosion is calculated as a function of daily stream flow volume and a regression coefficient. This regression coefficient is calculated as a function of the percentage of developed land, animal density, watershed-averaged soil erodibility, the watershed-averaged runoff curve number, and the total stream length. For the TMDL allocation scenarios, the reduction from restricting livestock access to streams was calculated as the product of the percentage of total stream length with livestock access, the percentage reduction of livestock access corresponding with the bacteria TMDL, and an estimated percentage of the channel erosion due to trampling, where livestock had stream access.

Sediment loads from point sources were calculated using TSS concentrations and flow volumes. For permitted Virginia Pollutant Discharge Elimination System (VPDES) facilities, available monthly daily monitoring report (DMR) data for each facility (Maximum Concentration and Maximum Daily Flow) were used to calculate TSS daily loads for each monthly sample. Sediment loads from 1000 gallon per day (gpd) general permit facilities were calculated as the number of facilities multiplied by the annual permitted TSS load for each facility.

1.3.6. Margin of Safety

The margin of safety (MOS) was explicitly modeled as 10% of the calculated TMDL to reflect the relative increase in uncertainty, compared to the MOS of 5% used previously in other TMDLs for the more complex modeling of fecal coliform.

1.3.7. Existing Conditions

The existing sediment loads were modeled for each watershed and are listed in Table 1.5 by land use category, percent of total watershed load, and sediment load unit area loads for individual landuses.

Table 1.5. Existing Sediment Loads

Surface Runoff Sources	Linville Creek (t/yr)	(%)	(t/ha-yr)	Upper Opequon Creek (t/yr)	(%)	(t/ha-yr)
High Till	14,014.3	39.5%	30.5	12,286.6	28.4%	20.9
Low Till	6,178.0	17.4%	13.4	4,138.3	9.6%	9.2
Hay	3,048.9	8.6%	1.1	2,263.2	5.2%	1.3
Pasture	5,360.0	15.1%	1.1	3,150.8	7.3%	0.6
Manure Acres	0.0	0.0%	0.0	0.0	0.0%	0.0
Forest	144.3	0.4%	0.0	204.7	0.5%	0.1
Disturbed Forest	158.7	0.4%	13.1	4,374.0	10.1%	15.9
Pervious Urban	54.6	0.2%	0.2	190.5	0.4%	0.1
Impervious Urban	77.8	0.2%	0.5	228.4	0.5%	0.2
Other Sources						
Channel Erosion	6,407.1	18.1%		16,412.2	37.9%	
Point Sources	1.6	0.0%		11.4	0.0%	
Watershed Totals						
Existing Sediment Load (t/yr)	35,445.2			43,260.0		
Area (ha)	12,015.2			15,044.5		
Unit Area Load (t/ha-yr)	2.950			**2.875**		
Target Sediment TMDL Load	**34,549.3**	**t/yr**				

The sediment TMDL for Linville Creek is the sum of the three required components – WLA, LA, and MOS - as quantified in Table 1.6.

Table 1.6. Linville Creek Sediment TMDL (t/yr)

TMDL	WLA	LA	MOS
34,549.3	5.5	31,088.8	3,454.9
	VA0085588 = 1.2455		
	VA0079898 = 2.9016		
	? SFH WLA = 1.3679		

The TMDL, or total maximum daily allowable load, was calculated as the watershed-based unit area load for the Upper Opequon Creek (2.875 t/ha-yr) multiplied by the area of the Linville Creek watershed (12,015.2 ha). To convert from t/yr to lbs/yr, multiply t/yr by 2,204.6.

1.3.8. Allocation Scenarios

To develop the allocation scenarios, sediment sources were grouped into the following four categories: Agriculture, Urban, Channel Erosion, and Point Sources. Because all Point Source sediment loads are permitted, and because

Urban sources contributed an insignificant amount of sediment (< 1%), no reductions were taken from these two categories. All allocation scenarios were developed, therefore, with reductions from the Agriculture and Channel Erosion categories.

Three alternative allocation scenarios were developed, as quantified in Table 1.7.

Table 1.7. Alternative Load Reduction Scenarios

Source Category	Existing (t/yr)	Linville Creek TMDL Sediment Load Allocations					
		TMDL Scenario 1		TMDL Scenario 2		TMDL Scenario 3	
		(% reduction)	(t/yr)	(% reduction)	(t/yr)	(% reduction)	(t/yr)
Agriculture	28,904.2	**15.1**	24,549.5	**12.3**	25,339.7	**9.6**	26,125.7
Urban	132.4	0.0	132.4	0.0	132.4	0.0	132.4
Channel Erosion	6,407.1	0.0	6,407.1	12.3	5,617.0	24.6	4,831.0
Point Sources	1.4		5.3		5.3		5.3
Total	**35,445.0**	12.3	31,094.4	12.3	31,094.4	12.3	31,094.4

Two sediment source categories in the watershed – Agriculture and Channel Erosion – were responsible for the majority of the sediment load in Linville Creek. The sediment TMDL for Linville Creek is 34,549 t/yr and will require an overall reduction of 12.3% from existing loads. TMDL Scenario 3 is the recommended alternative, because it accounts for the sediment reduction due to restricting livestock access to streams at the level called for in the companion bacteria TMDL, thus minimizing the remaining reduction needed to meet the TMDL from Agriculture.

The Linville Creek sediment TMDL was developed to meet the sediment unit area load of a selected reference watershed – Upper Opequon Creek. The TMDL was developed to take into account all sediment sources in the watershed from both point and nonpoint sources. The sediment loads were averaged over a 10-year period to take into account both wet and dry periods in the hydrologic cycle, and the model inputs took into consideration seasonal variations and critical conditions related to sediment loading. An explicit 10% margin of safety was added into the final TMDL load calculation.

1.3.9. Phase 1 Implementation

The reductions required from the bacteria TMDL phase 1 implementation plan will reduce the sediment loads to a level below those required for the final sediment TMDL. Therefore, the phase 1 implementation plan for sediment is the same as that for bacteria (Section 1.2.7).

1.4. Reasonable Assurance of Implementation

1.4.1. Follow-Up Monitoring

The Department of Environmental Quality (VADEQ) will continue to monitor Linville Creek in accordance with its ambient monitoring program. VADEQ and the Virginia Department of Conservation and Recreation (VADCR) will use data from Linville Creek monitoring stations to evaluate reductions in fecal bacteria counts and the effectiveness of the TMDL in attaining and maintaining water quality standards.

1.4.2. Regulatory Framework

The goal of this TMDL is to establish a three-step path that will lead to expeditious attainment of water quality standards. The first step in this process is to develop an implementable TMDL. The second step is to develop a TMDL implementation plan, and the final step is to implement the TMDL and attain water quality standards.

Section 303(d) of the Clean Water Act (CWA) and current USEPA regulations do not require the development of implementation strategies. However, including implementation plans as a TMDL requirement has been discussed for future federal regulations. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQ MIRA) directs VADEQ in section 62.1-44.19.7 to "*develop and implement a plan to achieve fully supporting status for impaired waters*". The Act also establishes that the implementation plan shall include that date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated cost, benefits and environmental impact of addressing the impairments. The US Environmental Protection Agency outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process". The listed elements include implementation actions/management measures, time line, legal or regulatory controls, time required to attain water quality standards, monitoring plan and milestones for attaining water quality standards. Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of VADEQ, VADCR, and other cooperating agencies.

Once developed, VADEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP), in accordance with the CWA's Section 303(e). In response to a Memorandum of Understanding (MOU) between USEPA and VADEQ, VADEQ also submitted a draft Continuous Planning Process to USEPA in which VADEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

1.4.3. Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. In response to the federal Clean Water Action Plan, Virginia developed a Unified Watershed Assessment that identifies watershed priorities. Watershed restoration activities, such as TMDL implementation, within these priority watersheds are eligible for Section 319 funding. Increases in Section 319 funding in future years will be targeted towards TMDL implementation and watershed restoration. Other funding sources for implementation include the USDA's Conservation Reserve Enhancement Program (CREP), the state revolving loan program, and the Virginia Water Quality Improvement Fund.

1.5. Public Participation

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. In May of 2002, members of the Virginia Tech TMDL group traveled to Rockingham County to become acquainted with the watershed. During that trip, the Virginia Tech TMDL group spoke with various stakeholders. In addition, personnel from Virginia Tech, the Headwaters Soil and Water Conservation District (SWCD), and the Natural Resource Conservation Service (NRCS) visited some watershed residents and contacted others via telephone to acquire their input. Two public meetings were held. The first public meeting was organized on September 26, 2002, at the Linville-Edom Elementary School, to inform the stakeholders of TMDL development process and to obtain feedback on animal numbers in the watershed, fecal production estimates and to discuss the hydrologic calibration. The draft TMDL report was discussed at the final public meeting held on March 5, 2003 at Broadway High School.

CHAPTER 2: INTRODUCTION

2.1. Background

2.1.1. TMDL Definition and Regulatory Information

Section 303(d) of the Federal Clean Water Act and the U.S. Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to identify water bodies that violate state water quality standards and to develop Total Maximum Daily Loads (TMDLs) for such water bodies. A TMDL reflects the total pollutant loading a water body can receive and still meet water quality standards. A TMDL establishes the maximum allowable pollutant loading from both point and nonpoint sources for a water body, allocates the load among the pollutant contributors, and provides a framework for taking actions to restore water quality.

2.1.2. Impairment Listing

Linville Creek is listed as impaired on Virginia's 1998 Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 1998) due to water quality violations of both

- the Fecal Coliform Standard, and
- the General Standard (listed as a benthic impairment).

The Virginia Department of Environmental Quality (VADEQ) has delineated the impairments on Linville Creek on a stream length of 13.55 miles. The impaired stream segment begins at the Linville Creek headwaters and continues downstream to its confluence with the North Fork of the Shenandoah River. Linville Creek is targeted for TMDL development and completion by 2004.

2.1.3. Watershed Location and Description

A part of the Potomac and Shenandoah River basin, Linville Creek watershed (Watershed ID VAV-B46R) is located in Rockingham County, Virginia, bounded by Broadway to the north and Harrisonburg to the south (Figure 2.1). The watershed is 29,647 acres in size. Linville Creek is mainly an agricultural watershed (about 71.3%) and is characterized by a rolling valley with the Blue Ridge Mountains to the east and the Appalachian Mountains to the west. The majority of the remaining 28.7% of the watershed area is divided between forest and rural developments. Linville Creek flows northeast and discharges into the North Fork of the Shenandoah River (USGS Hydrologic Unit Code 02070006), which is a tributary of the Potomac River; the Potomac River discharges into the Chesapeake Bay.

2.1.4. Pollutants of Concern

Pollution from both point and nonpoint sources can lead to fecal coliform bacteria contamination of water bodies. Fecal coliform bacteria are found in the intestinal tract of warm-blooded animals; consequently, fecal waste of warm-blooded animals contains fecal coliform. Even though most fecal coliform are not pathogenic, their presence in water indicates contamination by fecal material. Because fecal material may contain pathogenic organisms, water bodies with high fecal coliform counts are potential sources of pathogenic organisms. For contact recreational activities, e.g., boating and swimming, health risks increase with increasing fecal coliform counts in the water body. If the fecal coliform concentration in a water body exceeds state water quality standards, the water body is listed for violation of the state fecal coliform standard for contact recreational uses. As will be discussed in Section 2.2.2, the state has moved to an *Escherichia coli (E. coli)* standard for water quality. The concentration of *E. coli* (a subset of the fecal coliform group) in the water is considered to be a better indicator of pathogenic exposure than the concentration of the entire fecal coliform group in the water body.

Pollution from both point and nonpoint sources can also lead to a violation of the general standard for water quality (Section 2.2.4). This violation is assessed on the basis of measurements of the benthic macro-invertebrate community in the stream, with pollution impacts referred to as a benthic impairment. Water bodies having a benthic impairment are not fully supportive of the aquatic life use designated for Virginia's waters.

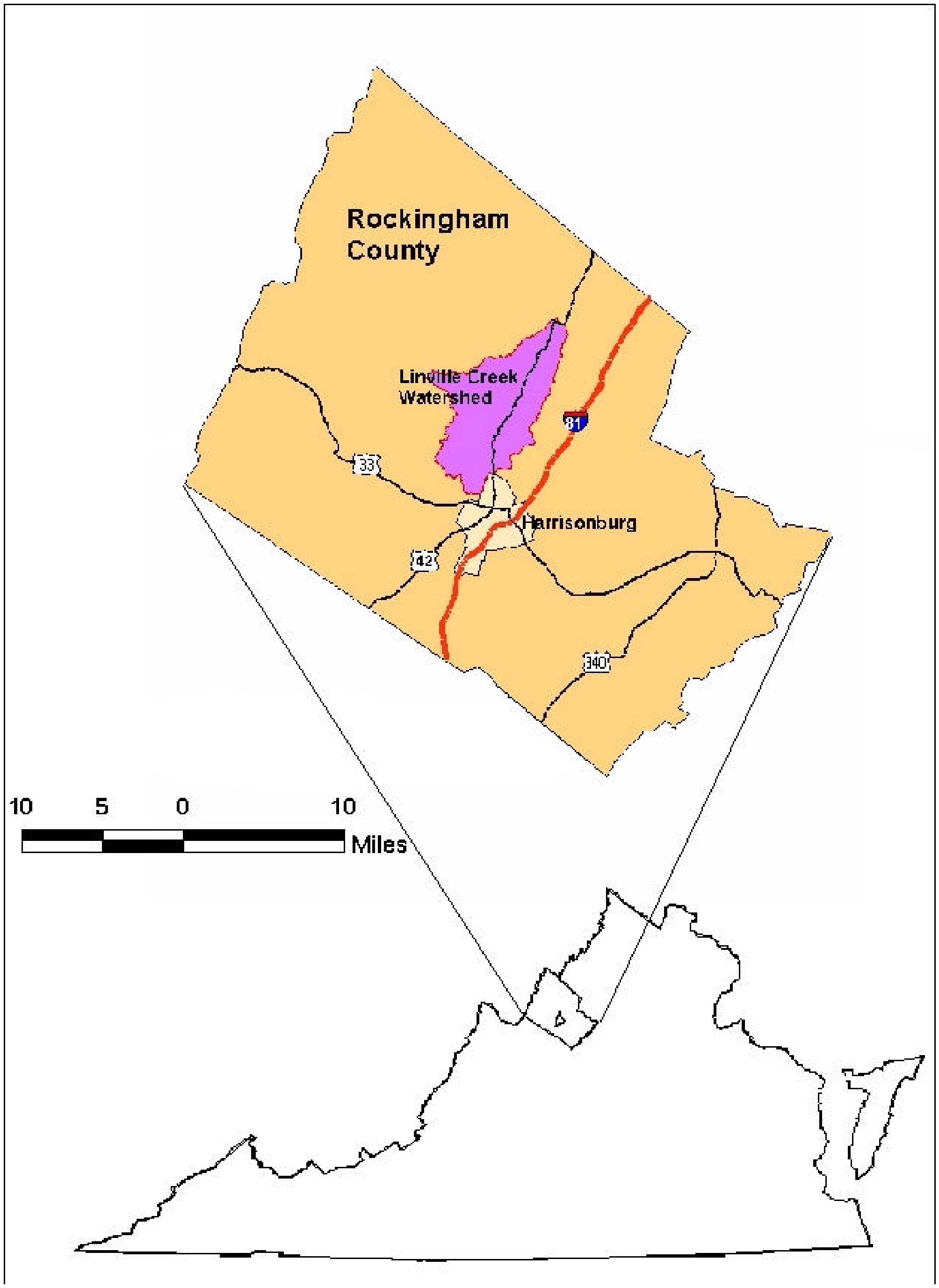


Figure 2.1. Location of Linville Creek watershed.

2.2. Designated Uses and Applicable Water Quality Standards

2.2.1. Designation of Uses (9 VAC 25-260-10)

> “A. All state waters are designated for the following uses: recreational uses (e.g. swimming and boating); the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish).” SWCB, 2002.

Linville Creek does not support the recreational (swimming) and aquatic life designated uses due to violations of the bacteria criteria and the general (benthic) criteria (Table 2.1).

Table 2.1. Linville Creek Impairments.

Segment ID	County	Station ID	Year Initially Listed	Impairment		
				Cause	Source	Length
VAV-B46R LNV01A00	Rockingham	1BLNV001.22	1998	General Standard (Benthic)	NPS - Agriculture	13.55 miles
VAV-B46R LNV01A00	Rockingham	1BLNV001.22	1998	Fecal Coliform	NPS – Agriculture/Wildlife	13.55 miles

2.2.2. Bacteria Standard (9 VAC 25-260-170)

EPA has recommended that all States adopt an *E. coli* or enterococci standard for fresh water and enterococci criteria for marine waters, because there is a stronger correlation between the concentration of these organisms (*E. coli* and enterococci) and the incidence of gastrointestinal illness than there is with fecal coliform. *E. coli* and enterococci are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals and are subsets of the fecal coliform and fecal streptococcus groups, respectively. In line with this recommendation, Virginia adopted and published revised bacteria criteria on June 17, 2002. The revised criteria became effective on January 15, 2003. As of that date, the *E. coli* standard described below applies to all freshwater streams in Virginia. Additionally, prior to June 30, 2008, the interim fecal coliform standard must be applied at any sampling station that has fewer than 12 samples of *E. coli*.

For a non-shellfish water body to be in compliance with Virginia's revised bacteria standards (as published in the Virginia Register Volume 18, Issue 20) the following criteria shall apply to protect primary contact recreational uses:

Interim Fecal Coliform Standard:

> Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 mL of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 mL of water.

***Escherichia coli* Standard**:

> *E. coli* bacteria concentrations for freshwater shall not exceed a geometric mean of 126 counts per 100 mL for two or more samples taken during any calendar month and shall not exceed an instantaneous single sample maximum of 235 cfu/100mL.

During any assessment period, if more than 10% of a station's samples exceed the applicable standard, the stream segment associated with that station is classified as impaired and a TMDL must be developed and implemented to bring the station into compliance with the water quality standard. The original impairment to Linville Creek was based on exceedences of an earlier fecal coliform standard that included a numeric single sample maximum limit of 1000 cfu/100 mL. Because the TMDL must be based on current standards, and because more than 12 samples of *E. coli* are available for Linville Creek, the TMDL will be developed to meet the *E. coli* standard. As recommended by VADEQ, the modeling will be conducted with fecal coliform inputs, and then a translator equation will be used to convert the output to *E. coli*.

2.2.3. General Standard (9 VAC 25-260-20)

The general standard for a water body in Virginia states:

> "A. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere

> directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life.
>
> Specific substances to be controlled include, but are not limited to: floating debris, oil scum, and other floating materials; toxic substances (including those which bioaccumulate); substances that produce color, tastes, turbidity, odors, or settle to form sludge deposits; and substances which nourish undesirable or nuisance aquatic plant life. Effluents which tend to raise the temperature of the receiving water will also be controlled." SWCB, 2002.

The first paragraph of this standard describes the designated uses for a water body in Virginia. Linville Creek is violating the general standard for aquatic life use, and thus has a general standard (benthic) impairment.

The Department of Environmental Quality runs the Biological Monitoring Program in Virginia. Evaluations of monitoring data from the program focus on the benthic (bottom-dwelling) macro (large enough to see with the naked eye) invertebrates (insects, mollusks, crustaceans, and annelid worms) and are used to determine whether or not a stream segment is supporting the aquatic life use. Changes in water quality generally result in changes in the types and numbers of the benthic organisms that live in streams and other water bodies. Besides being the major intermediate constituent of the aquatic food chain, benthic macro-invertebrates are "living recorders" of past and present water quality conditions. This is due to their relative immobility and their variable resistance to the diverse contaminants that can be introduced into streams. The community structure of these organisms provides the basis for the biological analysis of water quality. Qualitative and semi-quantitative biological monitoring has been conducted by VADEQ since the early 1970's. The USEPA Rapid Bioassessment Protocol II (RBP II) was employed beginning in the fall of 1990 to utilize standardized and repeatable methodology. For any single sample, the RBP II produces water quality ratings of "non-impaired," "slightly impaired," "moderately impaired," and "severely impaired." In Virginia, benthic samples are generally taken and analyzed twice a year, in the spring and in the fall.

The RBP II procedure evaluates the benthic macro-invertebrate community by comparing ambient monitoring network stations to reference sites.

A reference site is one that has been determined to be representative of a natural, unimpaired water body. The RBP II evaluation also accounts for the natural variation noted in streams in different ecoregions (regions that share characteristics such as meteorological factors, elevation, plant and animal speciation, landscape position, and soils). One additional product of the RBP II evaluation is a habitat assessment. This assessment provides information on the comparability of each stream station to the reference site.

Determination of the degree of support for the aquatic life use is based on conventional water column pollutants (DO, pH, temperature), sediment and nutrient screening value analyses, biological monitoring data, and the best professional judgment of the regional biologist, relying mostly on the most recent data collected during the current 5-year assessment period. In Virginia, any stream segment with an overall rating of “moderately impaired” or “severely impaired” is placed on the state’s 303(d) list of impaired streams (VADEQ, 2002).

CHAPTER 3: WATERSHED CHARACTERIZATION

3.1. Water Resources

The Linville Creek Watershed was subdivided into 11 sub-watersheds for fecal coliform modeling purposes, as shown in Figure 3.1. Tributaries to the impaired segment (Linville Creek B46-1,2,5,7,8,11) include Daphna Creek (B46-03), Joes Creek (B46-06), West Fork Linville Creek (B46-10), Tide Spring Branch (B46-04), and an unnamed tributary (B46-09). The main branch of Linville Creek runs for 13.55 miles from the headwaters until it enters the North Fork of the Shenandoah River. Linville Creek is perennial and has a trapezoidal channel cross-section. From September 1993 through September 2001, measured discharge ranged from 4,700 cubic feet per second (cfs) to 1.7 cfs, with a mean value of 40.5 cfs. Aquifers in this watershed are overlain by limestone (VWCB, 1985). Depth to the water table is in excess of 6 ft (SCS, 1982). The presence of numerous solution cavities with intensive agricultural use results in a high potential for groundwater pollution (VWCB, 1985).

3.2. Ecoregion

The Linville Creek watershed is located in the Central Appalachian Ridges and Valleys Level III Ecoregion. It is located primarily in the Northern Limestone/Dolomite Valleys Level IV Ecoregion, with a small portion located in the Northern Sandstone Ridges Level IV Ecoregion. The Central Appalachian Ridges and Valleys Ecoregion is characterized by its generation from a variety of geological materials. The Level III Ecoregion has numerous springs and caves. The ridges tend to be forested, while limestone valleys are composed of rich agricultural land (USEPA, 2002). The Northern Limestone/Dolomite Valleys Level IV ecoregion has fertile land and is primarily agricultural. Steeper areas have scattered forests composed mainly of oak trees. Streams tend to flow year-round and have gentle slopes. The Northern Sandstone Ridges Level IV ecoregion has steep ridges. Streams have steep slopes and a tendency toward being acidic. The ecoregion is composed primarily of Appalachian Oak Forest or Oak-Hickory-Pine forest (Woods *et al.*, 1999).

Figure 3.1. Linville Creek Sub-Watersheds.

3.3. Soils and Geology

The predominant soil groups found in Linville Creek watershed are the Frederick-Lodi-Rock outcrop, Endcav-Carbo-Rock outcrop, and Chilhowie-Edom soils (SCS, 1982). The Frederick-Lodi-Rock outcrop (silty loam) soils are deep and well drained with clayey subsoil and areas of rock outcrop (SCS, 1982). The EndCav-Carbo-Rock outcrop and Chilhowie-Edom soils are moderately-deep to deep, well-drained soils with clayey subsoil with areas of rock outcrop (SCS, 1982). In upland areas, each of these soils is underlain by limestone bedrock; Frederick-Lodi-Rock outcrop soils are also underlain by dolomite bedrock, and Chilhowie-Edom soils are also underlain by interbedded shale (SCS, 1982). These three general soil map units are found on gently sloping to steep topography with medium to rapid surface runoff (SCS, 1982).

3.4. Climate

The climate of the watershed is characterized based on the meteorological observations made by the National Weather Service's stations in the communities of Dale Enterprise and Timberville. Dale Enterprise, the primary source of climatic data for Linville Creek, is located 1.5 miles southwest of Linville Creek. Average annual precipitation at that station is 35.26 in. with 58% of the precipitation occurring during the crop-growing season (May-October) (SERCC, 2002). Average annual snowfall is 24.8 in. with the highest snowfall occurring during January (SERCC, 2002). Average annual daily temperature is 53.4°F. The highest average daily temperature of 73.7°F occurs in July while the lowest average daily temperature of 32.5°F occurs in January (SERCC, 2002).

3.5. Land Use

Pasture is the main land use category in Linville Creek, comprising 49% of the total watershed area, while cropland accounts for about 21% of the watershed area. Forest acreage accounts for about 16% of the total area. Residential and urban developments, which cover 9% of the total area, are spread throughout the watershed and are slightly concentrated near the outlet.

3.6. Stream Flow Data

Daily flow rates were available from USGS station 01632082 located near the mouth of Linville Creek. Monitoring at this station began on August 9, 1985 and ended on September 30, 2001.

3.7. Water Quality Data

Virginia DEQ monitored chemical and bacterial water quality in the watershed on a monthly basis from September 1993 through June 2001. From July 2001 through April 2002, data were collected on a bimonthly basis. Data on biological communities were collected semi-annually from October 1994 through May 2002. In conjunction with water quality monitoring, VADEQ conducted daily stream flow monitoring from August 1985 through September 2001. Stream flow data for the flow monitoring period and bacterial water quality data were both available for the period of September 1993 through September 2001.

3.7.1. Historic Data – Fecal Coliform

The Virginia Department of Conservation and Recreation has assessed this watershed as having a high potential for nonpoint source pollution from agricultural sources. Of the 102 water quality samples collected by VADEQ from September 1993 to April 2002 at the outlet of the watershed (Station ID No. 1BLNV001.22) (Figure 3.2), 34% exceeded the single sample maximum fecal coliform standard of 1,000 cfu/100 mL. Consequently, this segment of Linville Creek was assessed as not supporting the Clean Water Act's Swimming Use Support Goal for the 1998 305(b) report and was included in the 1998 303(d) list (USEPA, 1998a, b).

Virginia DEQ personnel monitored pollutant concentrations at the Linville Creek watershed outlet over eight and a half years (1993-2002) (VADEQ, 1997). From September 1993 through June 2001, samples were taken on a monthly basis; samples have been taken on a bimonthly basis since July 2001. Beginning in July

2001, samples were taken at two additional stations, 1BLNV006.49 and 1BLNV007.66. Twenty-three percent of the samples taken at 1BLNV006.49 violated the 1000 cfu/100mL fecal coliform standard, and 50% of the samples taken at 1BLNV007.66 violated the standard. These stations will be discontinued as of July 2003.

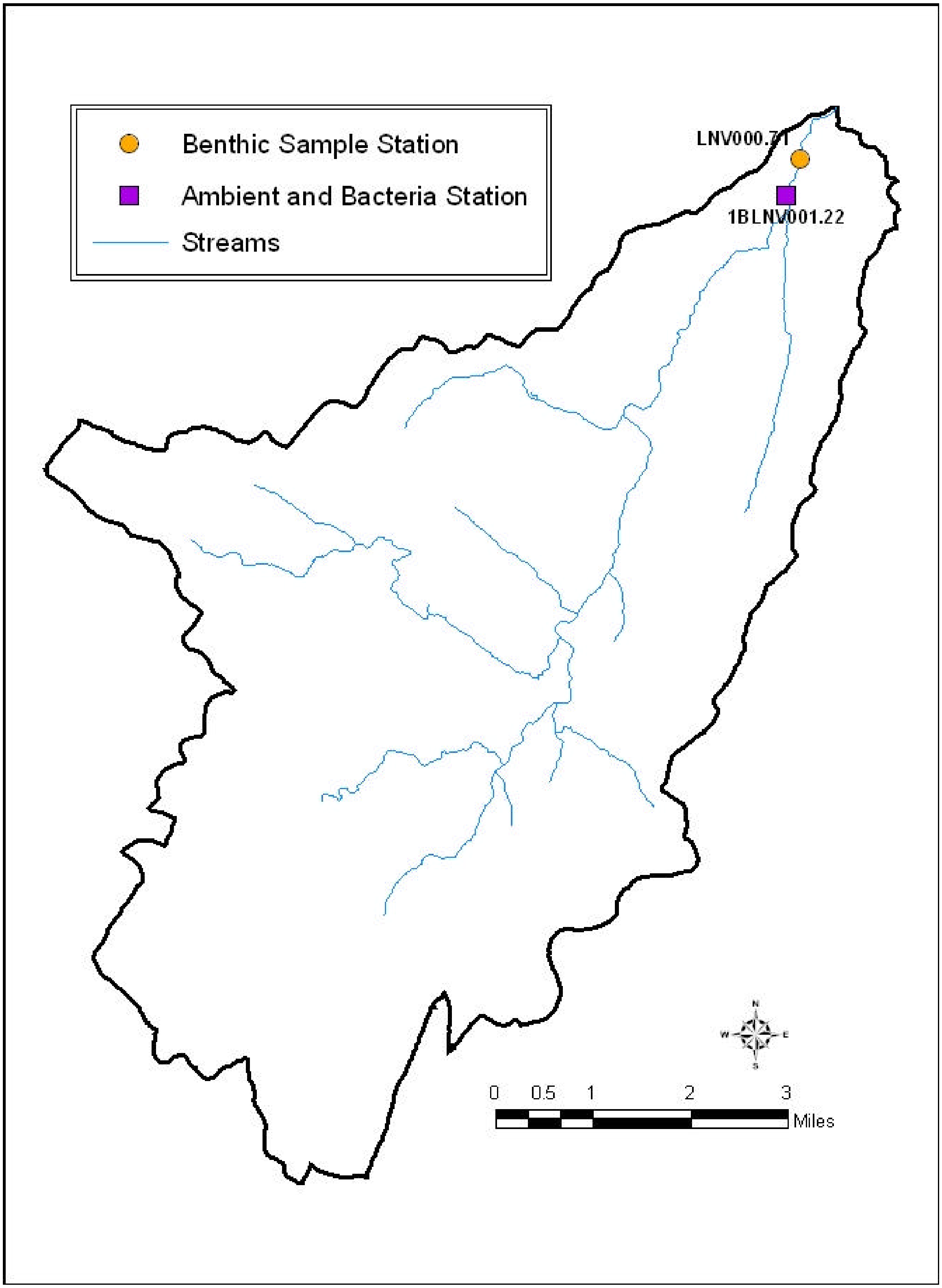


Figure 3.2. Location of sampling stations in the Linville Creek watershed.

In addition to fecal coliform, the water quality samples taken at station 1BLNV001.22 were analyzed for nitrate, total nitrogen, and total phosphorus. The 24 samples taken between January 2000 and April 2002 were also analyzed for *E. coli*. As mentioned in Section 2.2.2, any sampling station with more than 12 *E. coli* samples must attain the new bacteria standard for *E. coli*, rather than the old standard for fecal coliform. Therefore, the TMDL for Linville Creek must address the new *E. coli* standard. Time series data of fecal coliform concentration over the September 1993 through April 2002 period are shown in Figure 3.3. Time series data of *E. coli* concentration from January 2000 to April 2002 are shown in Figure 3.4.

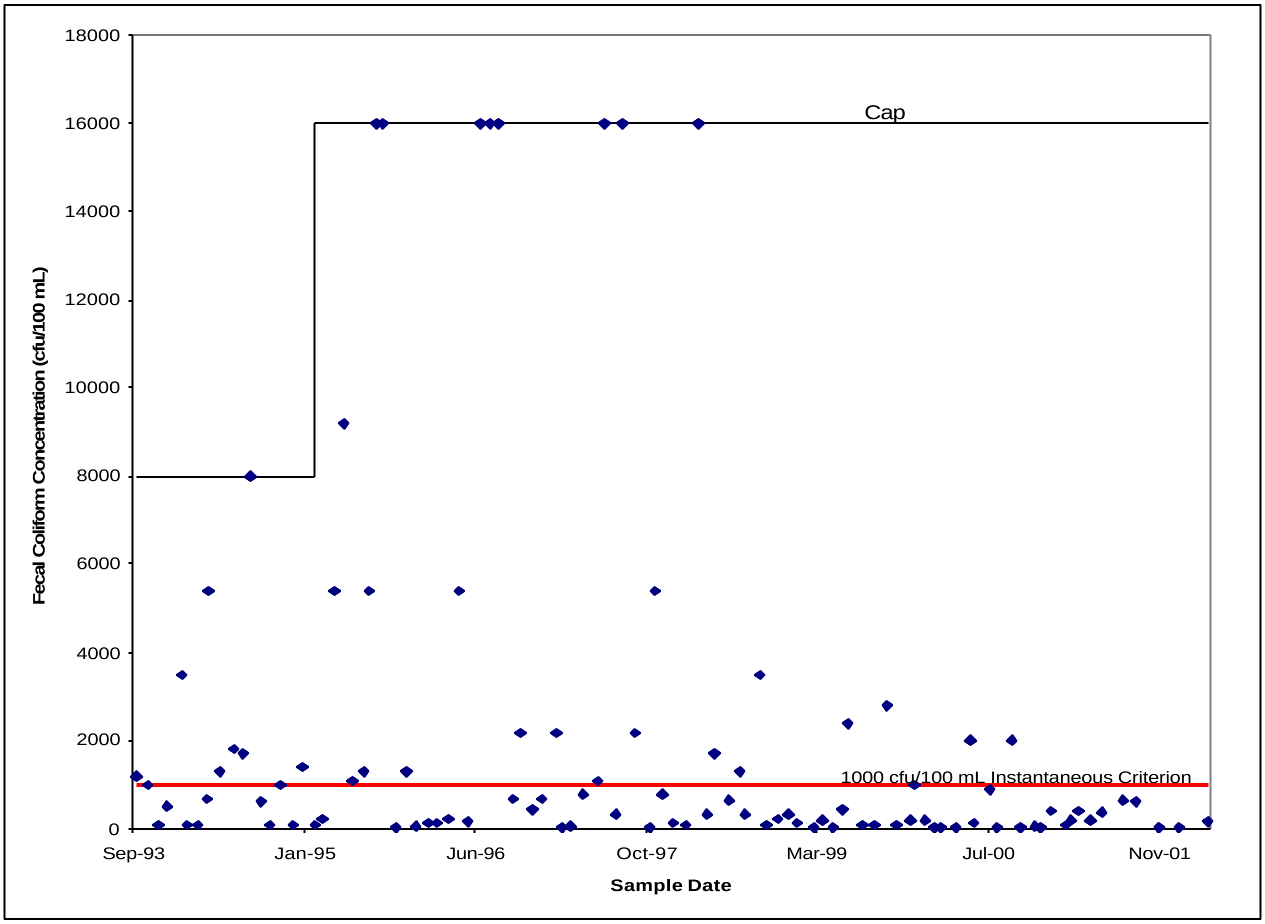


Figure 3.3. Time series of fecal coliform concentration in Linville Creek.

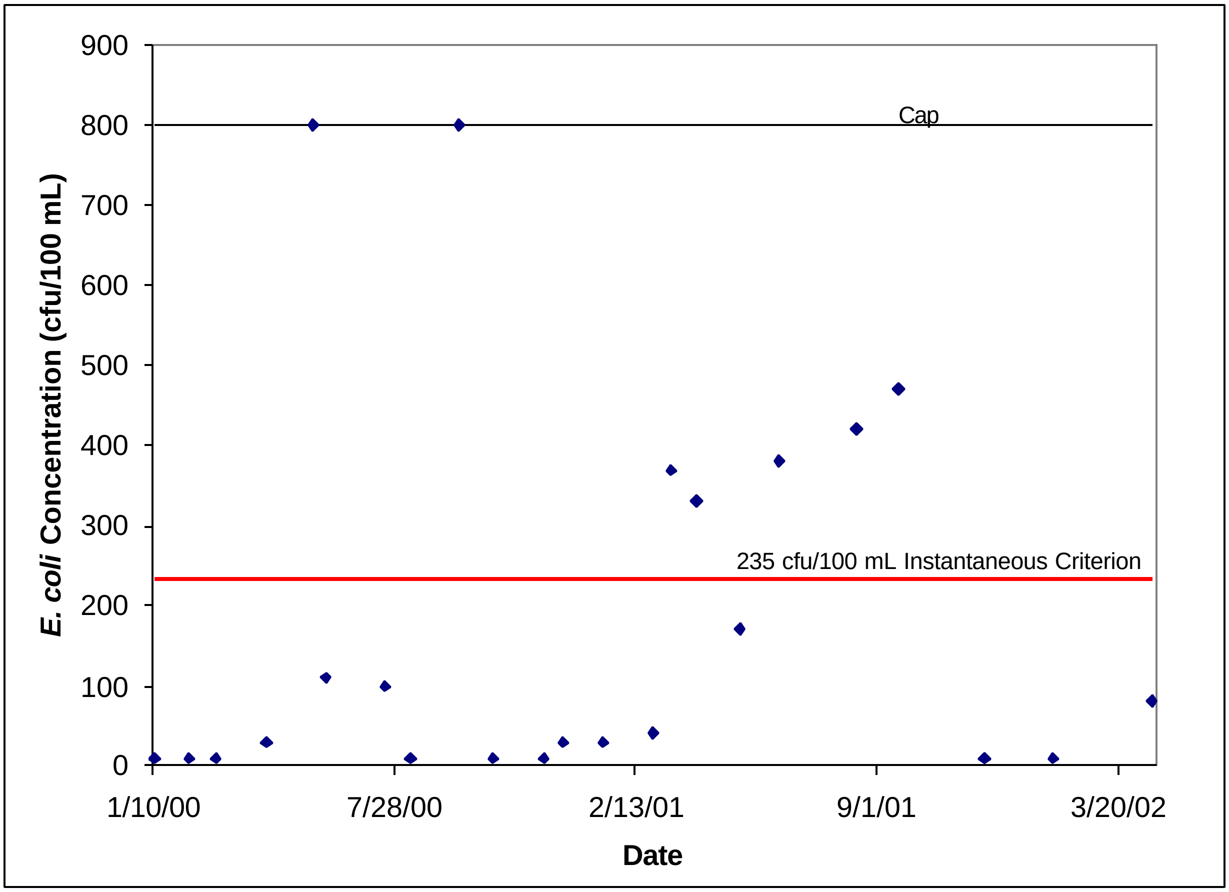


Figure 3.4. Time series of *E. coli* concentration in Linville Creek. Two samples were analyzed from November 28, 2001 and reported the same concentration, and thus only 23 points are visible on the graph.

Prior to March 1995, the Most Probable Number (MPN) method was used for analyzing water samples for fecal coliform concentration. The MPN method had a maximum detection limit of 8,000 cfu/100 mL. Another version of the MPN method was used after March 1995, which allowed detection of fecal coliforms up to a concentration of 16,000 cfu/100 mL. After October 2000, the more accurate Membrane Filtration Technique (MFT) was used for the analysis of fecal coliform in water samples. The MFT also has a maximum detection limit of 16,000 cfu/100 mL. The sample values shown at the maximum detection limit (Figure 3.3) indicate fecal coliform concentrations of at least 8,000 cfu/100 mL (prior to March 1995) or 16,000 cfu/100 mL. Similarly, the *E. coli* samples had a maximum detection limit of 800 cfu/100 mL. The sample values shown at the maximum detection limit (Figure 3.4) indicate *E. coli* concentrations of at least 800 cfu/100 mL. Violations of the fecal coliform water quality standard were observed throughout the reporting period.

Thirty-four percent of the 102 water samples collected by VADEQ from September 1993 through April 2002 contained fecal coliform concentrations in excess of the instantaneous standard of 1,000 cfu/100 mL (Figure 3.3). Nine percent of the samples contained the highest concentration of fecal coliform that could be measured by the method used. Given that water samples were collected on a monthly basis, the geometric mean criterion could not be calculated.

The relationship between stream flow rates and fecal coliform concentrations is shown in Figure 3.5. The stream flow rate and fecal coliform concentration data in Figure 3.5 are for the period from September 1993 through September 2001, when both data sets were available.

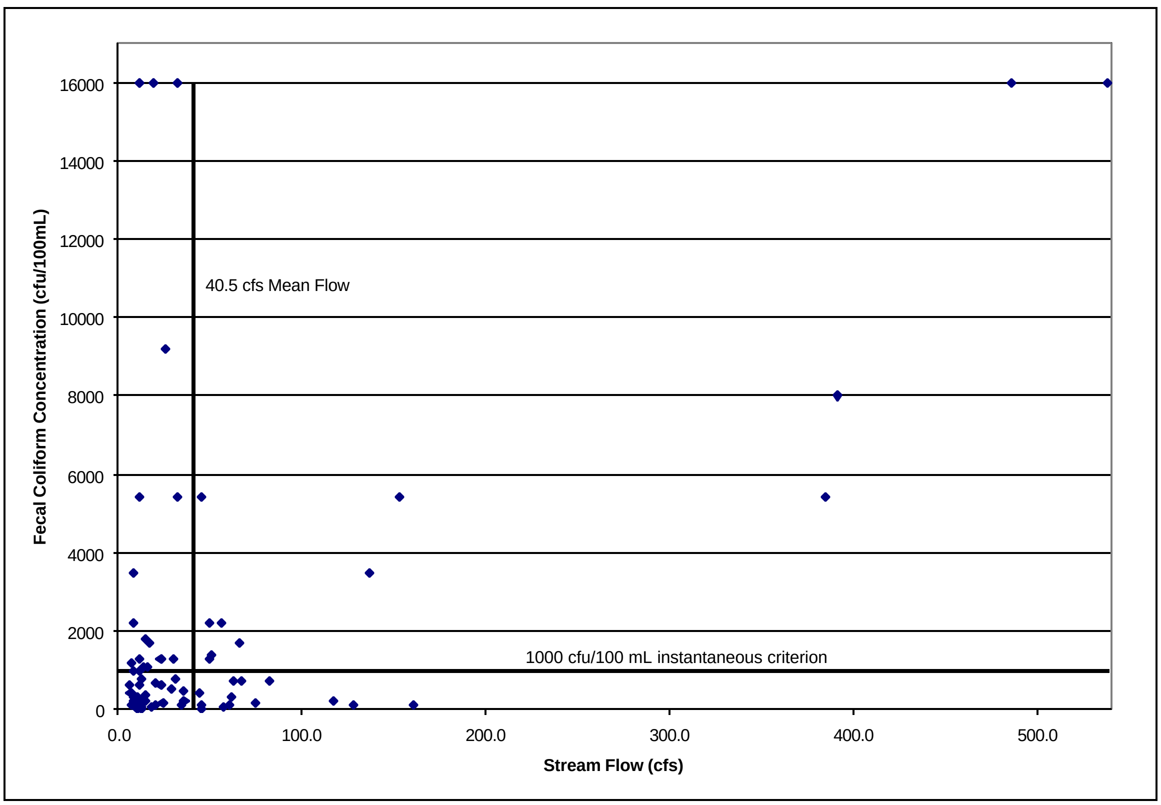


Figure 3.5. Relationship between stream flow and fecal coliform concentration from September 1993 through September 2001.

Based on daily flow measurements made from September 1993 through September 2001, mean stream flow in Linville Creek was 40.5 cfs. Thirty five of the 98 fecal coliform samples (35.7%) violated the instantaneous criterion during this time period, which is shorter than the total period due to the lack of flow data recorded after September 2001. Thirty percent of fecal coliform samples violated the instantaneous criterion of 1,000 cfu/100 mL (Figure 3.5) when flows were lower than the mean value of 40.5 cfs during this period. When flows exceeded the mean flow (40.5 cfs), 50% of the samples violated the instantaneous standard. However, most (75.5%) of the measurements were made when flow values were lower than the mean value. Higher fecal coliform concentrations under summer flow conditions (Figure 3.6) suggest that fecal coliform directly deposited/discharged into the stream may be the more dominant source as compared to fecal coliform coming in runoff from upland areas.

Seasonality of fecal coliform concentration in the streams was evaluated by plotting the mean monthly fecal coliform concentration values (Figure 3.6). Mean monthly fecal coliform concentration was determined as the average of eight to nine values for each month; the number of values varied according to the available number of samples for each month in the 1993 to 2001 period of record.

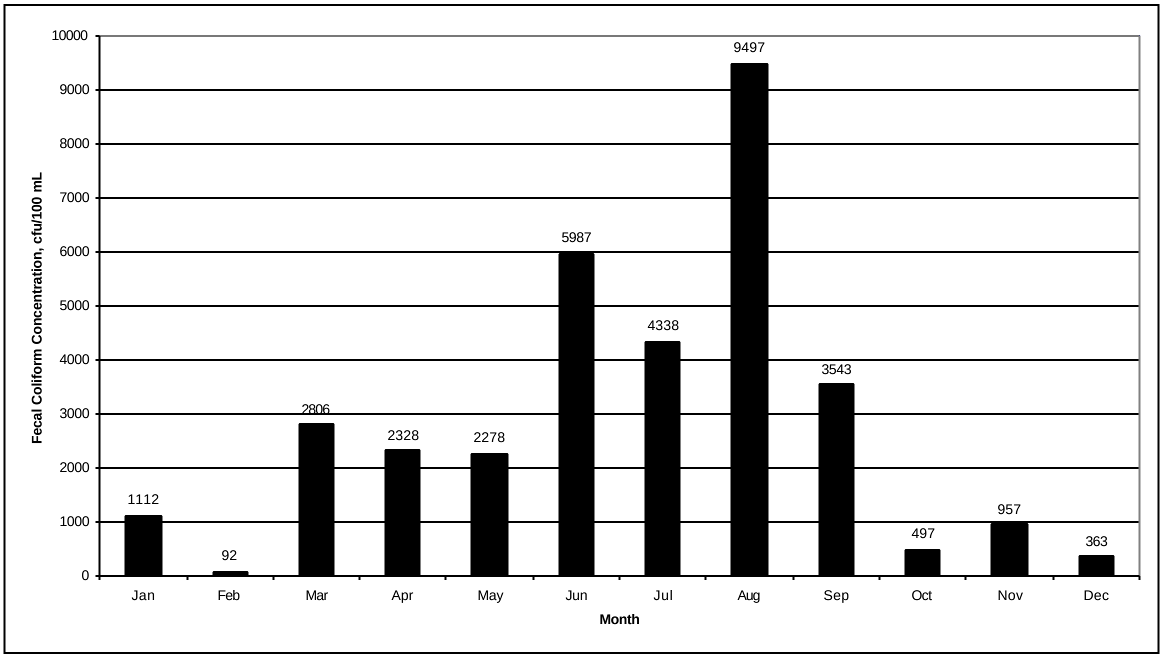


Figure 3.6. Impact of seasonality on fecal coliform concentrations.

The data indicate seasonal variability with higher in-stream fecal coliform concentrations occurring during the summer months and lower concentrations typically occurring during the winter months. During summer (June – August), the average fecal coliform concentration was 6,607 cfu/100mL compared with 522 cfu/100mL during winter (December – February). Lower fecal coliform concentrations measured during the winter and spring months (Figure 3.6) could be due to larger number of animals being in confinement during these periods, resulting in smaller fecal coliform loading to the pasture, and particularly to streams. Furthermore, land application of animal waste is limited during the winter months. Higher fecal concentrations during the summer and fall months (Figure 3.6) could be due to more cattle in streams and more animal waste land-applied during the fall. The high fecal coliform concentration observed during August (Figure 3.6) could also be due to a large proportion of animal waste being applied to crops during or prior to this month. Similarly, high fecal coliform concentrations observed in November (Figure 3.6) could be due to land-application of animal waste during the fall to a winter cover crop and/or to create space in a farm's waste storage facility for animal waste generated during winter. Again, it should be noted that due to the cap imposed on the fecal coliform count (8,000 or 16,000), where fecal coliform levels are equal to these maximum levels, the actual counts could be much higher, increasing the average shown in Figure 3.6.

3.7.2. Bacteria Source Tracking

Limited bacteria source tracking (BST) was conducted to aid in identification of potential sources of fecal bacteria in the Linville Creek watershed. The BST samples were collected at the DEQ ambient water quality monitoring station (1BLNV001.22) near the mouth of Linville Creek. The Antibiotic Resistance Analysis (ARA) procedure for enterococci was used in this study (Hagedorn *et al*., 1999). The monthly BST samples were collected from May through October 2002. A total of 6 samples were collected. It should be noted that this short sampling period was characterized by below normal precipitation, warm temperatures, and extremely low stream flows. The short time-frame available for field sample collection and the resulting small number of samples collected makes it difficult to draw any firm quantitative conclusions regarding bacteria sources in the Linville Creek watershed.

A total of 48 isolates were analyzed for each BST sample. Isolates from a few known sources (poultry, dairy, beef, goats, and human) in the watershed were collected to enhance the source database and improve the accuracy of the results for the Linville Creek watershed. The ARA results are reported as the percentage of isolates acquired from samples that were identified as originating from either human, livestock, cats/dogs, or wildlife sources (Table 3.1). The BST results indicate that dogs and cats are the major source of fecal bacteria, approximately 56%, in Linville Creek. Wildlife were identified as the second most significant source and accounted for approximately 33% of the fecal bacteria load. Livestock and human sources were found to contribute an average of 8 and 3% of the fecal bacteria load, respectively. Information in Table 3.1 suggest that the ARA method and/or the BST classification model results employed in the Linville Creek study should be viewed with great caution. One possible source of uncertainty is that the ARA method used enterococci as the fecal bacteria source indicator rather than *E* *coli* and fecal coliform bacteria used in previous TMDL studies. The wildlife, human and livestock numbers seem reasonable (plus or minus 15%) for the drought/low flow conditions at the time, but the cat and dog results are highly skeptical and do not represent the Linville conditions. As noted previously, the BST samples in the Linville Creek watershed were collected during extremely low stream flow conditions and warm temperatures, which precluded a comprehensive assessment of the impacts of land-based (manure applications, direct deposits) sources. Furthermore, due to the short time available for BST sample collection, no evaluation of the seasonal impacts could be made. Therefore, the results presented here for Linville are inconclusive as they are not representative of general watershed conditions.

Table 3.1. Linville Creek BST results.

Station	Date	Fecal Coliform Conc. (cfu/100mL)	Enterococci* Conc. (cfu/100mL)	General Categories (%)			
				Human	Livestock	Wildlife	Cats & Dogs
LC1	5/15/02	900	400	11	25	56	8
LC1	6/12/02	6,000	460	2	2	54	42
LC1	7/25/02	4,100	830	2	2	38	58
LC1	8/23/02	2,000	100	0	6	52	42
LC1	9/27/02	520	580	6	19	10	65
LC1	10/30/02	3,700	1,100	0	2	23	75
Percentage of total isolates				**3**	**8**	**33**	**56**

* Source database compiled from 152 isolates collected in the current project area and 2,030 isolates from other geographic areas. Average Rate of Correct Classification (ARCC) for the compiled database is 79%.

3.7.3. Historic Data – Benthic Macro-invertebrates

Two “moderately impaired” benthic ratings during the 5-yr assessment period (July 1, 1992-June 30, 1997) used for the 1998 303(d) assessment report resulted in the Linville Creek watershed being assessed as not supporting of the Aquatic Life designated use. VADEQ listed nonpoint source agricultural pollution as the probable cause of the benthic impairment (VADEQ, 1998).

The Rapid Bioassessment Protocol II (RBP II) is the index used to assess compliance with the general standard in Virginia. This protocol compares the conditions of a target stream to those of an unimpaired, or reference, watershed. Four different watersheds were used as references for Linville Creek. In Fall 1994 and Fall 1996, Jackson River was used as the reference watershed. In Spring and Fall of 1995, Stony Creek was used as the reference watershed. In Spring 1996, Fall 1998, and Spring 1999, Bullpasture Creek was used as the reference watershed. Finally, Cowpasture Creek was used in the three assessments made since Fall 2001. Of the ten assessments performed between October 1994 and May 2002, 7 received a rating of moderately impaired, as shown in Table 3.2. On October 2, 2001, the benthic monitoring station at Linville Creek was changed to a location further downstream that was determined by the regional biologist to provide a more representative benthic sample. The subsequent May 17, 2002 sample, as well as future samplings, will be collected at both the old and new sampling sites in order to establish a relationship between the two sites.

Table 3.2. Rapid Bioassessment Protocol II Scores for Linville Creek (LNV000.71 and LNV000.16)

RBP II	(Scores calculated against a reference watershed.)							LNV000.16	LNV000.16	
Sample Date	10/3/94	5/9/95	9/28/95	5/21/96	9/22/97	10/23/98	5/19/99	10/2/01	5/17/02	5/17/02
SampleNum	62	240	417	555	976	1324	1420	2932	2982	2981
a. RBP II Metric Values										
Taxa Richness	19	22	24	16	16	14	11	18	19	17
MFBI	5.06	5.05	4.90	5.41	6.36	5.54	5.20	4.41	5.02	6.87
SC/CF	0.67	0.47	1.76	0.37	1.51	5.46	11.68	2.14	1.65	0.92
EPT/Chi Abund	6.46	2.43	4.24	0.75	0.98	0.89	0.13	37.00	0.83	0.28
% Dominant	20.98	16.88	23.36	35.78	33.33	32.41	46.88	42.59	30.43	31.01
Dominant Species	Pleurocerida	Simuliidae	Elmidae	Chironomida	Planariidae	Pleurocerida	Chironomida	Elmidae		
EPT Index	6	6	5	7	6	4	4	6	7	4
Comm. Loss Index	0.63	0.55	0.33	0.56	1.00	0.64	1.18	0.65	0.32	0.65
SH/Tot	2.10	4.55	5.61	1.83	0.00	0.00	0.00	0.02	0.00	0.00
b. Reference Metric Values										
Station_ID	JKS067.00	STY006.73	STY006.73	BLP000.79	JKS067.00	BLP000.79	BLP000.79	CWP050.66	CWP050.66	CWP050.66
Reference Sample Date	10/24/94	5/9/95	10/2/95	5/20/96	10/6/97	10/7/98	5/13/99	10/13/01	5/6/02	5/6/02
Reference Sample_ID	61	268	444	548	971	1300	1408	2901	2969	2969
Taxa Richness	24	26	24	21	24	15	18	14	17	17
MFBI	3.22	3.80	4.20	3.24	3.41	4.25	4.34	3.84	3.94	3.94
SC/CF	1.04	2.01	3.46	1.27	1.20	2.38	1.20	1.26	9.00	9.00
EPT/Chi Abund	10.58	5.79	7.84	8.93	39.04	18.00	1.90	10.00	6.43	6.43
% Dominant	22.56	11.19	25.36	17.65	18.75	42.00	30.30	23.53	44.70	44.70
EPT Index	11	13	9	13	12	9	10	8	9	9
Comm. Loss Index										
SH/Tot	17.29	2.99	2.90	10.08	7.03	1.00	7.07	0.01	0.01	0.01
Reference Biological Score	46	48	46	48	48	42	44	46	42	42
c. RBP II Metric Ratios										
Taxa Richness	79.2	84.6	100.0	76.2	66.7	93.3	61.1	128.6	111.8	100.0
MFBI	63.6	75.3	85.7	59.8	53.7	76.8	83.5	87.1	78.4	57.4
SC/CF	64.1	23.4	50.7	29.5	126.0	228.8	973.0	169.8	18.3	10.2
EPT/Chi Abund	61.0	42.1	54.1	8.4	2.5	5.0	6.9	370.0	12.9	4.3
% Dominant	21.0	16.9	23.4	35.8	33.3	32.4	46.9	42.6	30.4	31.0
EPT Index	54.5	46.2	55.6	53.8	50.0	44.4	40.0	75.0	77.8	44.4
Comm. Loss Index	0.63	0.55	0.33	0.56	1.00	0.64	1.18	0.65	0.32	0.65
SH/Tot	12.1	152.3	193.5	18.2	0.0	0.0	0.0	185.2	0.0	0.0
d. RBP II Metric Scores										
Taxa Richness	4	6	6	4	4	6	4	6	6	6
MFBI	2	4	6	2	2	4	4	6	4	2
SC/CF	6	2	6	2	6	6	6	6	0	0
EPT/Chi Abund	4	2	4	0	0	0	0	6	0	0
% Dominant	4	6	4	2	2	2	0	0	2	2
EPT Index	0	0	0	0	0	0	0	2	2	0
Comm. Loss Index	4	4	6	4	4	4	4	4	6	4
SH/Tot	0	6	6	0	0	0	0	6	0	0
Total RBP II Score	24	30	38	14	18	22	18	36	20	14
% of Reference	52.17	62.50	82.61	29.17	37.50	52.38	40.91	78.26	47.62	33.33
RBP II Assessment	**Moderate**	**Slight**	**Slight**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Slight**	**Moderate**	**Moderate**

The Macroinvertebrate Aggregated Index for Streams (MAIS) is a secondary index whose metrics are also calculated by VADEQ, but it is only used as a supplemental indicator of stream quality. Individual MAIS metrics are rated against a fixed scale rather than against those of a reference watershed, as in the RBP II index. The various metrics, some of which duplicate those in the RBP II, along with their scores and final ratings are given for each sample in Table 3.3.

Table 3.3. Macroinvertebrate Aggregated Index for Streams Assessment Results for Linville Creek

MAIS (Scores calculated against a fixed scale. Values indicating the best conditions are shown at the far right.)

a. MAIS Metric Values											**Best Score**
Sample Date	10/3/94	5/9/95	9/28/95	5/21/96	9/22/97	10/23/98	5/19/99	10/2/01	5/17/02	5/17/02	**Category**
% 5 Dominant	66.43	61.04	57.01	81.65	85.00	82.41	92.97	61.04	76.09	76.74	<79.13
MFBI	5.06	5.05	4.90	5.41	6.36	5.54	5.20	5.00	5.02	6.87	<4.22
% Haptobenthos	73.43	68.83	64.49	47.71	33.33	57.41	44.53	57.10	58.70	23.26	>83.26
EPT Index	6	6	5	7	6	4	4	6	7	4	>7
# Mayfly Taxa	4	4	3	5	4	3	3	4	4	2	>3
% Mayfly Abundance	9.09	20.78	18.69	23.85	5.00	7.41	4.69	20.80	12.50	4.65	>17.52
Simpson's Diversity Index	0.90	0.92	0.91	0.82	0.81	0.83	0.71	0.92	0.84	0.84	>0.823
# Intolerant Taxa	13	15	17	10	8	6	6	15	9	6	>9
% Scraper Abundance	31.47	18.18	34.58	8.26	29.17	50.93	39.06	12.99	17.93	8.53	>10.7
b. MAIS Scores											
% 5 Dominant	2	2	2	1	1	1	1	2	2	2	
MFBI	1	1	1	1	0	1	1	1	1	0	
% Haptobenthos	1	1	1	0	0	1	0	1	1	0	
EPT Index	1	1	1	1	1	1	1	1	1	1	
# Mayfly Taxa	2	2	1	2	2	1	1	2	2	1	
% Mayfly Abundance	1	2	2	2	1	1	1	2	1	1	
Simpson's Diversity Index	2	2	2	1	1	1	1	2	2	2	
# Intolerant Taxa	2	2	2	2	1	1	1	2	1	1	
% Scraper Abundance	2	2	2	1	2	2	2	2	2	1	
Total MAIS Score	14	15	14	11	9	10	9	15	13	9	**18**
MAIS Assessment	**Good**	**Good**	**Good**	**Poor**	**Poor**	**Poor**	**Poor**	**Good**	**Good**	**Poor**	**Best**

A qualitative analysis of various habitat parameters was conducted in conjunction with each biological sampling. Each of the 10 parameters listed in Table 3.4 had a maximum score of 20 indicating the most desirable condition, and a score of 0 indicating the poorest habitat conditions.

Table 3.4. Habitat Evaluation Scores for Linville Creek

Linville Creek (LNV000.71)								LNV000.16	LNV000.16	
Habitat Evaluation Date	10/3/94	5/9/95	9/28/95	5/21/96	9/22/97	10/23/98	5/19/99	10/2/01	5/17/02	5/17/02
HabSampID	LNV51	LNV221	LNV381	LNV502	LNV862	LNV1172	LNV1240	LNV2621	LNV2664	LNV2663
ALTER	18	16	18	14	10	11	10	15	11	8
BANKS	10	14	14	10	6	2	8	17	14	12
BANKVEG	12	12	16	8	6	8	7	14	16	10
EMBED	6	8	10	12	10	0	2	8	11	2
FLOW	18	18	20	20	20	18	18	18	18	18
RIFFLES	8	10	8	10	10	16	3	17	16	10
RIPVEG	4	0	4	0	0	0	1	4	7	2
SEDIMENT	10	8	12	12	6	0	2	16	10	1
SUBSTRATE	8	10	10	10	8	15	8	16	17	5
VELOCITY	10	14	10	12	10	10	13	14	15	10
Total Habitat Score	104	110	122	108	86	80	72	139	135	78

*ALTER = channel alterations; BANKS = bank stability; BANKVEG = bank vegetation; EMBED = embeddedness; FLOW = flow quantity; RIFFLES = presence of riffles; RIPVEG = riparian vegetation; SEDIMENT = abundance of bottom sediment; SUBSTRATE = availability of firm, clean stream bottom surfaces; VELOCITY = velocity of flow.

CHAPTER 4: SOURCE ASSESSMENT OF FECAL COLIFORM

Fecal coliform sources in the Linville Creek watershed were assessed using information from the following sources: VADEQ, VADCR, Virginia Department of Game and Inland Fisheries (VADGIF), Virginia Cooperative Extension (VCE), NRCS, public participation, watershed reconnaissance and monitoring, published information, and professional judgment. Point sources and potential nonpoint sources of fecal coliform are described in detail in the following sections and summarized in Table 4.1.

4.1. Humans and Pets

The Linville Creek watershed has an estimated population of 4,930 people (1815 households at an average of 2.717 people per household; actual people per household varies according to sub-watershed). Fecal coliform from humans can be transported to streams from failing septic systems or via straight pipes discharging directly into streams.

Table 4.1. Potential fecal coliform sources and daily fecal coliform production by source in Linville Creek watershed.

Potential Source	Population in Watershed	Fecal coliform produced ($\times 10^6$ cfu/head-day)
Humans	4,930	1,950[a]
Dairy cattle		
Milk and dry cows	1,446	20,200[b]
Heifers [c]	891	9,200[d]
Beef cattle	6,511	20,000
Pets	1,815	450[e]
Poultry		
Broilers	11,096,408	136[f]
Turkey Toms	719,457	93[f]
Sheep		
Ewes	425	12,000[f]
Lambs	850	
Goats	60	
Horses	64	420[f]
Deer	1,394	0.0725
Raccoons	631	50
Muskrats	729	25[g]
Beavers	39	0.2
Wild Turkeys	264	93[f]
Ducks	224	0.0725
Geese	263	0.0725

[a] Source: Geldreich *et al*. (1978)
[b] Based on data presented by Metcalf and Eddy (1979) and ASAE (1998)
[c] Includes calves
[d] Based on weight ratio of heifer to milk cow weights and fecal coliform produced by milk cow
[e] Source: Weiskel *et al*. (1996)
[f] Source: ASAE (1998)
[g] Source: Yagow (2001)

4.1.1. Point Sources

Point sources of fecal coliform bacteria in the Linville Creek watershed include all municipal and industrial plants that treat human waste, as well as private residences that fall under general permits. Virginia issues National Pollutant Discharge Elimination System (NPDES) permits for point sources of pollution. In Virginia, point sources that treat human waste are required to maintain a fecal coliform concentration of 200 cfu/100 mL (126 cfu/100 mL *E. coli*) or less in their effluent. Tables 4.2 (VPDES permits) and 4.3 (general permits) show the point sources of pollution in the Linville Creek watershed that are permitted by VADEQ to discharge fecal coliform and sediment into surface water. In allocation scenarios, the entire allowable point source discharge concentration of 200 cfu/100 mL was used.

Table 4.2. VPDES Permits in Linville Creek.

Permit Number	Owner	Facility	Receiving Stream	Sub-Watershed	Flow (MGD)	River Mile	Permitted FC Conc.	FC Load (cfu/year)	Permitted TSS Conc.	TSS Load (t/yr)
VA0085588	Virginia Department of Corrections	Field Unit #8 STP	Linville Creek	B46-03	0.03	7.64	200 cfu/ 100 mL	$8.29*10^{10}$	30 mg/L	1.24
VA0079898	Town of Broadway	Broadway WTP	Linville Creek	B46-01	0.07	0.07	NA	NA	30 mg/L	2.90

NA = not applicable; does not discharge fecal coliform

Table 4.3. General Permits discharging into Linville Creek.

Permit Number	Facility Name	City	Discharge Type	Sub-Watershed	Design Flow (gpd)	Permitted FC Conc. (cfu/100 mL)	FC Load (cfu/year)	Permitted TSS Conc. (mg/L)	TSS Load (t/year)
VAG401780	Homeowner, Route 42 N	Edom	Retired (RET)[a]	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG401911	Homeowner, E of SR 765/910 intersection		Single Family House (SFH)	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG401169	Homeowner, SR 910/765		RET	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG401198	Homeowner, Route 42, N of Harrisonburg		SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG401378	Homeowner, 4055 Linville-Edom Road	Linville	SFH	B46-09	1000	200	$2.76*10^9$	30	0.0415
VAG401561	Homeowner, 13672 South Sunset Drive	Broadway	SFH	B46-01	1000	200	$2.76*10^9$	30	0.0415
VAG401694	Homeowner, 122 Holly Hill Street		SFH	B46-01	1000	200	$2.76*10^9$	30	0.0415
VAG401747	Homeowner, N of Harrisonburg, Route 42	Harrisonburg	SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG401748	Homeowner, N of Harrisonburg, Route 42	Harrisonburg	SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG401749	Homeowner, N of Harrisonburg, Route 42	Harrisonburg	SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG401750	Homeowner, N of Harrisonburg, Route 42	Harrisonburg	SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG401751	Homeowner, N of Harrisonburg, Route 42	Harrisonburg	SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG401752	Homeowner, N of Harrisonburg, Route 42		SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG401753	Homeowner, N of Harrisonburg, Route 42		SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG401770	Homeowner, N of Harrisonburg, Route 42	Harrisonburg	SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG401785	Homeowner, W side 910, just N of 763		SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415

Table 4.3. General Permits discharging into Linville Creek. **(cont.)**

VAG401801	Homeowner, SR 910, NW of Harrisonburg		SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG401825	Homeowner, Route 753	Linville	SFH	B46-09	1000	200	$2.76*10^9$	30	0.0415
VAG401889	Homeowner, E of Route 42, about 0.75 mi N of City limits	Harrisonburg	SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG401898	Homeowner, E side of SR 910, ~ 0.75 mile N of Route 33		SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG401904	Homeowner, W side of SR 910, N of SR 765	Harrisonburg	SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG401964	Homeowner, E side of Route 42 intersection with SR 762		SFH	B46-05	1000	200	$2.76*10^9$	30	0.0415
VAG401965	Homeowner, S side SR 768, 0.3 mi W of SR 910	Harrisonburg	SFH	B46-10	1000	200	$2.76*10^9$	30	0.0415
VAG401971	Homeowner, Lot #1, W side Rt 42, 0.1 mi N of SR 765 (east)		SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG401972	Homeowner, Lot #2, W side Rt 42, 0.1 mi N of SR 765 (east)		SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG401987	Business, 2591 Harpine Highway	Harrisonburg	Private (PRVT)	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG401990	Homeowner, South Side Rt 768,.3 miles west of 910	Harrisonburg	SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG401995	Homeowner, South side of Route 721, .2 miles west of Route 753	Linville	SFH	B46-09	1000	200	$2.76*10^9$	30	0.0415
VAG408039	Homeowner, E. side of Route 910 approx 1 mile N of Route 763	Harrisonburg	SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG408033	Homeowner, E. side of Route 910 approx 1/4 mi south of Route 765	Harrisonburg	SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG408021	Homeowner, E. side of RT. 778 0.3 miles south of Rt. 779	Harrisonburg	SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG408007	Homeowner, South side of Route 768, 0.3 miles west of route 910	Harrisonburg	SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415
VAG408040	Homeowner, 5036 Turner's Mill Lane	Harrisonburg	SFH	B46-11	1000	200	$2.76*10^9$	30	0.0415

[a]Retired facilities are included in the TMDL to allow for future increases in general permitted facilities.

4.1.2. Failing Septic Systems

Septic system failure can be evidenced by the rise of effluent to the soil surface. It was assumed that no die-off occurred once effluent containing fecal coliform reached the soil surface. Surface runoff can transport the effluent containing fecal coliform to receiving waters. Sewered areas were located using Autocad drawings from the town of Broadway and watershed reconnaissance. Three hundred sixteen households were located in sewered areas; these households' waste systems were not assumed to be a source of fecal coliform contamination. Unsewered households were located using E-911 digital data, (see Glossary) (Rockingham Co. Planning Dept., 2001). Each unsewered household was classified into one of three age categories (pre-1967, 1967-1987, and post-1987) based on USGS 7.5-min. topographic maps which were initially created using 1967 photographs and were photo-revised in 1987. Professional judgment was applied in assuming that septic system failure rates for houses in the pre-1967, 1967-1987, and post-1987 age categories were 40, 20, and 3%, respectively (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, Va.). Estimates of these failure rates were also supported by the Holmans Creek Watershed Study (a watershed located just north of Linville Creek), which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (SAIC, 2001).

Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average occupancy rate for that sub-watershed (occupancy rate ranged from 2.29 to 3.06 persons per household (Census Bureau, 2000)) by the per capita fecal coliform production rate of 1.95×10^{9} cfu/day (Geldreich *et al.*, 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a sub-watershed with an occupancy rate of 2.29 persons/household was 4.47×10^{9} cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur. The number of failing septic systems in the watershed is given in Table 4.4.

4.1.3. Straight Pipes

Of the houses located within 150 ft of streams, in the pre-1967 and 1967-1987 age categories, 10%, and 2%, respectively, were estimated to have straight pipes (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, Va.). Based on these criteria, it was estimated that the watershed had 4 straight pipes.

4.1.4. Pets

Assuming one pet per household, there are 1815 pets in Linville Creek watershed. A dog produces fecal coliform at a rate of 0.45×10^9 cfu/day (Weiskel *et al.*, 1996); this was assumed to be representative of a 'unit pet' – one dog or several cats. The pet population distribution among the sub-watersheds is listed in Table 4.4. Pet waste is generated in the rural residential and urban residential land use types. Surface runoff can transport bacteria in pet waste from residential areas to the stream.

Table 4.4. Estimated number of unsewered houses by age category, number of failing septic systems, and pet population in Linville Creek watershed.

Sub-watershed	Unsewered houses in each age category (no.)[a]			Failing septic systems (no.)	Pet population[b]
	Pre-1967	1967-1987	Post-1987		
B46-01	19	17	13	11.4	50
B46-02	31	11	35	15.7	77
B46-03	59	28	39	30.4	129
B46-04	30	13	43	15.9	87
B46-05	58	25	51	29.7	135
B46-06	98	30	126	49	255
B46-07	4	3	3	2.3	10
B46-08	30	1	6	12.4	37
B46-09	107	36	92	52.8	258
B46-10	96	55	87	52	238
B46-11	115	52	81	58.8	539
Total	647	271	576	330.4	1815

[a] Five households were estimated to have straight pipes, and 316 households were sewered. Adding these numbers to the numbers above yields the total number of households, 1815.

[b] Assumed an average of one pet per household. Includes pets from sewered households.

4.2. Cattle

Fecal coliform in cattle waste can be directly excreted to the stream, or it can be transported to the stream by surface runoff from animal waste deposited on pastures or applied to crop and hay land.

4.2.1. Distribution of Dairy and Beef Cattle in the Linville Creek Watershed

There are fifteen dairy farms in the watershed, based on reconnaissance and information from the Virginia Department of Agricultural and Consumer Services (VDACS). From communication with local dairy farmers, it was determined that there are 1,339 milk cows, 107 dry cows, and 891 heifers in the watershed (Table 4.1). The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farms (Table 4.5). Table 4.5 shows the number of dairy operations for each sub-watershed.

Table 4.5. Distribution of dairy cattle, dairy operations and beef cattle among Linville Creek sub-watersheds.

Sub-watershed	Dairy cattle	No. of dairy operations	Beef cattle
B46-01	0	0	121
B46-02	431	2	484
B46-03	0	0	814
B46-04	0	0	400
B46-05	0	0	1455
B46-06	0	0	1111
B46-07	0	0	13
B46-08	0	0	66
B46-09	125	1	468
B46-10	545	4	779
B46-11	1,236	8	798
Total	2,337	15	6,511

Beef cattle in the watershed included cow/calf and feeder operations. The exact number of beef operations in the watershed is not known; the beef cattle population (6,511 cattle) in the watershed was estimated based on communication with Dr. Dan Eversole, the beef specialist at Virginia Tech (August 14, 2002), regarding stocking rates for various pasture categories. The stocking rates were particular to the classification of pasture areas. In the following discussion and throughout this report, pasture 1 represents the VADCR land use classification “improved pasture.” Pasture 2 corresponds to “unimproved pasture” and Pasture 3 to “overgrazed pasture.” The following procedure was used to estimate beef population by sub-watershed (Table 4.5).

1. Based on communication with Dr. Dan Eversole, it was assumed that the ratio of the stocking rates for pasture types 1, 2, and 3 was 4:2:1. This means that pasture 2 had a stocking rate twice that of pasture 3, and that pasture 1 had a stocking rate twice that of pasture 2.

2. The stocking rates of the three pasture types were determined as a combination of information on the carrying capacity of the pastures and data from VADCR. Beef cattle stocking rates for pastures 1, 2, and 3 were 0.71, 0.36, and 0.18 beef cattle/acre, respectively.

3. The number of beef cattle in each pasture category was calculated by multiplying the pasture acreage by the stocking rate for that pasture category. This was done only for pasture acreage not occupied by dairy cows.

Beef and dairy cattle spend varying amounts of time in confinement, loafing lots, streams, and pasture depending on the time of year and type of cattle (i.e., milk cow versus heifer). Accordingly, the proportion of fecal coliform deposited in any given land area varies throughout the year. Based on discussions with NRCS, VADCR, VCE, and local producers, the following assumptions and procedures were used to estimate the distribution of cattle (thus their manure) among different land use types and in the stream.

a) Cows are confined according to the schedule given in Table 4.6.

b) When the milk cows are not confined or in loafing lots, they spend 100% of the time on pasture. All other dairy (dry cows and heifers) and beef cattle are also on pastures when not in confinement or loafing lots. Dairy cows only occupy pasture 1.

c) Pasture 1 (improved pasture/hayland) stocks twice as many cows per unit area as pasture 2 (unimproved pasture/grazed woodlands), which stocks twice as many cows per unit area as pasture 3 (overgrazed pasture).

d) Cows on pastures that are contiguous to streams (2,409 acres for all pasture categories, Table 4.7), have stream access.

e) Cows with stream access spend varying amounts of time in the stream during different seasons (Table 4.6). Cows spend more time in the stream during the three summer months to protect their hooves from hornflies, among other reasons.

f) Thirty percent of cows in and around streams directly deposit fecal coliform into the stream. The remaining 70% of the manure is deposited in pastures.

Table 4.6. Time spent by cattle in confinement and in the stream.

Month	Time spent in confinement (%)		Time spent in the stream (hours/day)[a]
	Milk cows	Dry cows, heifers, and beef cattle	
January	75%	40%	0.50
February	75%	40%	0.50
March	40%	0%	0.75
April	30%	0%	1.00
May	30%	0%	1.50
June	30%	0%	3.50
July	30%	0%	3.50
August	30%	0%	3.50
September	30%	0%	1.50
October	30%	0%	1.00
November	40%	0%	0.75
December	75%	40%	0.50

[a] Time spent in and around the stream by cows that have stream access.

Table 4.7. Pasture acreages contiguous to stream.

Sub-watershed	Pasture 1		Pasture 2		Pasture 3	
	Acres	%[a]	Acres	%[a]	Acres	%[a]
B46-01	10.3	6%	3.1	80%	0	0%
B46-02	128.5	15%	0	0%	0	0%
B46-03	88.5	11%	0	0%	445.7	51%
B46-04	137.2	31%	3.5	3%	37.0	19%
B46-05	309.4	18%	39.1	16%	107.7	13%
B46-06	445.8	34%	45.8	24%	213.3	35%
B46-07	0	0%	0.1	22%	0	0%
B46-08	17.4	20%	1.0	96%	0	0%
B46-09	94.7	16%	0.3	<1%	14.1	22%
B46-10	58.1	6%	41.4	17%	59.6	10%
B46-11	95.6	8%	1.0	<1%	10.7	1%
Total	1385.5	17%	135.3	8%	888.1	19%

[a] Percent of pasture area contiguous to stream to the total pasture area of that type in that sub-watershed.

A sample calculation for determining the dairy cattle numbers to different land use types and stream in sub-watershed B46-02 is shown in Appendix B. The resulting numbers of cattle in each land use type as well as in the stream for all sub-watersheds are given in Table 4.8 for dairy cattle and in Table 4.9 for beef cattle.

Table 4.8. Distribution of the dairy cattle[a] population.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[b]	Loafing[c]
January	1403.5	872.8	0.0	0.0	0.1	60.6
February	1403.5	872.8	0.0	0.0	0.1	60.6
March	535.6	1655.4	0.0	0.0	0.5	145.5
April	401.7	1764.5	0.0	0.0	1.0	169.8
May	401.7	1764.0	0.0	0.0	1.5	169.8
June	401.7	1762.4	0.0	0.0	4.1	169.8
July	401.7	1762.4	0.0	0.0	4.1	169.8
August	401.7	1762.4	0.0	0.0	4.1	169.8
September	401.7	1762.4	0.0	0.0	2.1	169.8
October	401.7	1763.5	0.0	0.0	1.5	169.8
November	535.6	1655.4	0.0	0.0	0.5	145.5

December	1403.5	872.8	0.0	0.0	0.1	60.6

[a] Includes milk cows, dry cows, and heifers.
[b] Number of dairy cattle defecating in stream.
[c] Milk cows in loafing lot.

Table 4.9. Distribution of the beef cattle population.

Months	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[a]	Loafing
January	2221.3	2625.8	271.7	364.1	0.7	69.8
February	2607.7	3082.5	318.9	427.4	0.8	81.9
March	0.0	5287.9	547.2	733.2	3.6	140.5
April	0.0	5437.1	562.6	753.9	7.3	144.6
May	0.0	5586.1	578.1	774.6	11.3	148.6
June	0.0	5722.3	592.4	793.6	30.8	152.7
July	0.0	5873.9	608.1	814.6	31.7	156.7
August	0.0	6025.5	623.7	835.6	32.5	160.7
September	0.0	3190.7	640.7	858.4	16.7	164.8
October	0.0	3800.0	393.3	526.9	7.7	101.1
November	0.0	3994.5	413.3	553.8	2.7	106.2
December	2124.8	2511.6	259.9	348.2	0.7	66.7

[a] Number of beef cattle defecating in stream.

4.2.2. Direct Manure Deposition in Streams

Direct manure loading to streams is due to both dairy (Table 4.8) and beef cattle (Table 4.9) defecating in the stream. However, only cattle on pastures contiguous to streams have stream access. Manure loading increases during the warmer months when cattle spend more time in water, compared to the cooler months. Average annual manure loading directly deposited by cattle in the stream for the watershed is 315,071 lb. Daily fecal coliform loading due to cows depositing in the stream, averaged over the year, is 2.7×10^{11} cfu/day. Part of the fecal coliform deposited in the stream stays in the dissolved form while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that dissolved fecal coliform bacteria are the primary form transported with the flow. Sediment-bound fecal coliform bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions.

Die-off of fecal coliform in the stream depends on sunlight, predation, turbidity, and other environmental factors.

4.2.3. Direct Manure Deposition on Pastures

Dairy (Table 4.8) and beef (Table 4.9) cattle that graze on pastures but do not deposit in streams contribute the majority of fecal coliform loading on pastures. Manure loading on pasture was estimated by multiplying the total number of each type of cattle (milk cow, dry cow, heifer, and beef) on pasture by the amount of manure produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Because the confinement schedule of the cattle changes with season, manure and fecal coliform loading on pasture also change with season.

Pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 17,681; 5,918; and 3,065 lb/ac-year, respectively. The loadings vary because stocking rate varies with pasture type. Fecal coliform loadings from cattle on a daily basis, averaged over the year, are 1.5×10^{10}, 7.9×10^{9}, and 2.8×10^{9} cfu/ac-day for pastures 1, 2, and 3, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

4.2.4. Land Application of Liquid Dairy Manure

A typical milk cow weighs 1,400 lb and produces 17 gallons of liquid manure daily (ASAE, 1998). Based on the monthly confinement schedule (Table 4.6) and the number of milk cows (Section 4.2.1), annual liquid dairy manure production in the watershed is 3.6 million gallons. Based on per capita fecal coliform production of milk cows, the fecal coliform concentration in fresh liquid dairy manure is 1.18×10^{9} cfu/gal. Liquid dairy manure receives priority over other manure types (poultry litter and solid cattle manure) in application to land. Liquid dairy manure application rates are 6,600 and 3,900 gal/ac-year to cropland and pasture land use categories, respectively, with cropland receiving priority in application. Based on availability of land and liquid dairy manure, as well as the assumptions regarding application rates and priority of application, it was estimated that liquid dairy manure was applied to 539 acres (8.5%) of cropland. Because there was more than enough crop area to receive the liquid manure produced in the watershed, no liquid dairy manure was applied to pasture.

The typical crop rotation in the watershed is a seven-year rotation with three years of corn-rye and four years of rotational hay. It was assumed that 50% of the corn acreage was under no-till cultivation. Liquid manure is applied to cropland during February through May (prior to planting) and in October-November (after the crops are harvested). For spring application to cropland, liquid manure is applied on the soil surface to rotational hay and no-till corn, and is incorporated into the soil for corn in conventional tillage. In fall, liquid manure is incorporated into the soil for cropland under rye, and surface-applied to cropland under rotational hay. In all months except December and January, liquid manure can be surface-applied to pasture 1. It was assumed that only 10% of the subsurface-applied fecal coliform was available for removal in surface runoff based on local knowledge. The application schedule of liquid manure is given in Table 4.10. Dry cows and heifers were assumed to produce only solid manure.

Table 4.10. Schedule of cattle and poultry waste application in the Linville Creek watershed.

Month	Liquid manure applied (%)[a]		Solid manure or poultry litter applied (%)[a]	
	Crops	Pasture	Crops	Pasture
January	0	0	0	0
February	7.1	5	6.7	5
March	35.7	25	33.3	25
April	28.6	20	26.7	20
May	7.1	5	6.7	5
June	0	10	0	5
July	0	0	0	5
August	0	5	0	5
September	0	15	0	10
October	7.1	5	13.3	10
November	14.3	10	13.3	10
December	0	0	0	0

[a] As percent of annual load applied to each land use type.

4.2.5. Land Application of Solid Manure

Solid manure produced by dry cows, heifers, and beef cattle during confinement is collected for land application. It was assumed that milk cows produce only liquid manure while in confinement. The number of cattle, their typical weights, amounts of solid manure produced, and fecal coliform concentration in fresh manure are given in Table 4.11. Solid Manure is last on the priority list for application to land (it falls behind liquid manure and poultry litter). The amount of solid manure produced in each sub-watershed was estimated based on the populations of dry cows, heifers, and beef cattle in the sub-watershed (Table 4.5) and their confinement schedules (Table 4.6). Solid manure from dry cows, heifers, and beef cattle contained different fecal coliform concentrations (cfu/lb) (Table 4.11).

Table 4.11. Estimated population of dry cows, heifers, and beef cattle, typical weights, per capita solid manure production, and fecal coliform concentration in fresh solid manure in individual cattle type.

Type of cattle	Population	Typical weight (lb)	Solid manure produced (lb/animal-day)	Fecal coliform concentration in fresh manure (× 10^6 cfu/lb)
Dry cow	107	1,400[a]	115.0[b]	176[c]
Heifer	891	640[d]	40.7[a]	226[c]
Beef	6,511	1,000[e]	60.0[b]	333[c]

[a] Source: ASAE (1998)
[b] Source: MWPS (1993)
[c] Based on per capita fecal coliform production per day (Table 4.1) and manure production
[d] Based on weighted average weight assuming that 57% of the animals are older than 10 months (900 lb ea.), 28% are 1.5-10 months (400 lb ea.) and the remainder are less than 1.5 months (110 lb ea.) (MWPS, 1993).
[e] Based on input from local producers

Solid manure is applied at the rate of 12 tons/ac-year to both cropland and pasture, with priority given to cropland. As in the case of liquid manure, solid manure is only applied to cropland during February through May, October, and November. Solid manure can be applied to pasture during the whole year, except December and January. The method of application of solid manure to cropland or pasture is assumed to be identical to the method of application of liquid dairy manure. The application schedule for solid manure is given in Table 4.10. Based on availability of land and solid manure, as well as the assumptions regarding application rates and priority of application, it was estimated that solid cattle manure was applied to 310 acres (4.9%) of the cropland, 230 acres (2.8%) of pasture 1, and 54 acres (3%) of pasture 2. Because the areas of cropland, pasture 1, and pasture 2 were more than adequate to accommodate the solid manure application, solid manure was not applied to pasture 3.

4.3. Poultry

The poultry population (Table 4.1) was estimated based on the permitted combined feeding operations (CAFO) located within the watershed and discussions with local producers and nutrient management specialists. The permitted CAFOs are included in Appendix I. Poultry litter production was estimated from the poultry population after accounting for the time when the houses are not occupied (Table 4.12). It is not known which poultry litter (broiler or broiler breeder or turkey) is applied to land. Hence, a weighted average fecal coliform concentration was estimated for poultry litter based on relative proportions of litter from all poultry types and their respective fecal coliform contents (Table 4.12).

Table 4.12. Estimated daily litter production, litter fecal coliform content for individual poultry types, and weighted average fecal coliform content.

Poultry Type	Typical Weight(lb)[a]	Production cycles (per year)[b]	Occupancy factor[c]	Litter produced per bird		Fecal coliform content ($\times 10^9$ cfu/lb)[f]	Weighted average fecal coliform content ($\times 10^9$ cfu/lb)
				(lb/cycle)[d]	(lb/day)[e]		
Broiler Breeder[g]	4	1.09	0.96	30.0	0.09	1.46	0.86
Broiler	2	6	0.79	2.6	0.04	1.65	
Turkey	15	5	0.87	18.0	0.25	0.33	

[a] Source: ASAE (1998)
[b] Based on information from VADCR and producers
[c] Fraction of time when the poultry house is occupied; layer – 46 weeks/48 weeks; broiler – 48 days/61 days; turkey (5 cycles) – 45 weeks/52 weeks
[d] Source: VADCR (1993)
[e] Litter produced per bird per day is equal to the product of production cycles per year and litter produced per cycle divided by number of days in a year.
[f] Fecal content in litter is equal to fecal coliform produced per day per bird (Table 4.1) multiplied by the occupancy factor, divided by the litter produced per day per bird.
[g] Broiler Breeders were considered equivalent to Layers.

Because poultry is raised entirely in confinement, all litter produced is collected and stored prior to land application. The estimated production rate of poultry litter in the Linville Creek watershed is 41.7×10^6 lb/year, which corresponds to a fecal coliform production rate of 3.6×10^{16} cfu/year. Poultry litter is applied at the rate of 3 tons/ac-year first to cropland, and then to pastures at the same rate. Poultry litter receives priority after all liquid manure has been applied (i.e., it is applied before solid cattle manure is considered). The method of poultry litter application to cropland and pastures is assumed to be identical to the method of cattle manure application. Application schedule of poultry litter is given in Table 4.10. As with liquid and solid manures, poultry litter is not applied to cropland during June through September. Based on availability of land and poultry litter, as well as the assumptions regarding application rates and priority of application, it was estimated that poultry litter was applied to 4,907 acres (77%) of cropland; 2,019 acres (25%) of pasture 1; and 29 acres (1.6%) of Pasture 2. Pasture 3 did not receive any poultry litter because there was insufficient poultry litter to apply to the entire cropland, pasture 1, and pasture 2 areas.

4.4. Sheep and Goats

The sheep and goat populations (Table 4.1) were estimated based on discussions with nutrient management specialists and observations of the watershed. The sheep herd was composed of lambs and ewes. The lamb population was expressed in equivalent sheep numbers. The equivalent sheep population calculated for lambs was based on the assumption that the average weight of a lamb is half of the weight of a sheep. The lamb population for the Linville Creek watershed was estimated to be 850 animals. The equivalent sheep population for the lambs was 425. A similar approach was used for goats. The equivalent number of sheep for goats was calculated based on the ratio of animal weights. It was assumed that the average weight for a goat and a sheep were 140 lb and 60 lb, respectively (ASAE, 1998). The equivalent number of goats (140) was calculated as the ratio of the goat weight to the sheep weight (140/60) times the number of goats in the watershed (60). The total number of sheep for the Linville Creek watershed was the sum of the number of ewes (425), equivalent number of lambs (425), and the equivalent number of goats (140), for a total of 990 animals. The sheep were kept on pastures 1 and 2. The relative stocking density for sheep was estimated to be 0.4 for pasture 1 and 0.6 for pasture 2 based on discussions with local producers. The equivalent sheep population for each sub-watershed is shown in Table 4.13. Sheep and goats are not usually confined and tend not to wade or defecate in the streams. Therefore, the fecal coliform produced by sheep and goats was added to the loads applied to pastures 1 and 2.

Table 4.13. Sheep and Goat Populations in Linville Creek Sub-Watersheds.

Sub-watershed	Goat	Ewe	Lamb
B46-01	20	0	0
B46-02	0	0	0
B46-03	0	100	200
B46-04	0	0	0
B46-05	0	115	230
B46-06	0	50	100
B46-07	0	20	40
B46-08	0	50	100
B46-09	0	0	0
B46-10	0	40	80
B46-11	40	50	100
Total	60	425	850

Pasture 1 and pasture 2 have average annual sheep manure loadings of 59 and 179 lb/ac-year, respectively. The loadings vary because stocking density varies with pasture type. Fecal coliform loadings from sheep on a daily basis averaged over the year are $8.05x10^8$ cfu/ac-day and $9.48x10^8$ cfu/ac-day for pastures 1 and 2, respectively.

4.5. Horses

Horse populations for the Linville Creek watershed were obtained through observations of the watershed and communication with local producers. The total horse population was estimated to be 64. The distribution of horse population among the sub-watersheds is listed in Table 4.14. Horses are not usually confined and tend not to wade or defecate in the streams. Therefore, the fecal coliform produced by horses was added to the loads applied to the three pasture types. Fecal coliform loadings from horses on a daily basis averaged over the year and over pasture areas in the entire watershed are $1.82x10^6$ cfu/ac-day, $1.86x10^6$, and $1.85x10^6$ cfu/ac-day for pastures 1, 2, and 3, respectively.

Table 4.14. Horse Populations among Linville Creek Sub-Watersheds.

Sub-watershed	Horse Population
B46-01	10
B46-02	6
B46-03	0
B46-04	0
B46-05	0
B46-06	4
B46-07	0
B46-08	0
B46-09	0
B46-10	20
B46-11	24
Total	64

4.6. Wildlife

Wildlife fecal coliform contributions can be from excretion of waste on land and from excretion directly into streams. Information provided by VADGIF, professional trappers, and watershed residents were used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, goose, and wood duck. Population numbers for each species and fecal coliform amounts were determined (Table 4.1) along with preferred habitat and habitat area (Table 4.15).

Professional judgment was used in estimating the percent of each wildlife species depositing directly into streams, considering the habitat area each occupied (Table 4.15). Fecal matter produced by deer that is not directly deposited in streams is distributed among pastures and forest. Raccoons deposit their waste in streams and forests. Muskrats deposit their waste in streams, forest, and cropland.

Fecal loading from wildlife was estimated for each sub-watershed. The wildlife populations were distributed among the sub-watersheds based on the area of appropriate habitat in each sub-watershed. For example, the deer population was evenly distributed across the watershed, whereas the 66 ft buffer around streams and impoundments in forest and crop areas determined the muskrat population. Therefore, a sub-watershed with more stream length and impoundments and more area in forest and crop land use would have more muskrats than a sub-watershed with shorter stream length and fewer impoundments, and less area in forest and crop land use. Distribution of wildlife among sub-watersheds is given in Table 4.16.

Table 4.15. Wildlife habitat description and acreage, and percent direct fecal deposition in streams.

Wildlife type	Habitat	Acres of habitat	Population Density (animal/ac-habitat)	Direct fecal deposition in streams (%)
Deer	Entire Watershed	29,647	0.047	0.1%
Raccoon	600 ft buffer around streams and impoundments	9,013	0.07	3.2%
Muskrat	66 ft buffer around streams and impoundments in forest and cropland	265	2.75	3.2%
Beaver	300 ft buffer streams and impoundments in forest and pasture	2,553	0.015	50%
Geese[a]	300 ft buffer around main streams	2395	0.078 – off season 0.1092 – peak season	2.5%
Wood Duck[a]	300 ft buffer around main streams	2395	0.0624 – off season 0.0936 – peak season	2.5%
Wild Turkey	Entire Watershed except urban and farmstead	25,800	0.01	1%

[a] Based on estimates provided by Professional Trapper (R. Spiggle, personal communication, October 2001, Blacksburg, Va.)

Table 4.16. Distribution of wildlife among sub-watersheds.

Sub-watershed	Deer	Raccoon	Muskrat	Beaver	Geese	Wood Duck	Wild Turkey
B46-01	42	16	9	1	11	9	2
B46-02	120	78	125	4	25	21	23
B46-03	132	59	27	4	26	22	23
B46-04	73	38	93	3	24	20	14
B46-05	204	101	71	7	43	37	40
B46-06	217	98	125	8	57	49	42
B46-07	8	9	32	0	7	6	1
B46-08	15	10	17	0	7	6	2
B46-09	84	32	44	2	19	16	14
B46-10	235	92	85	5	21	18	46
B46-11	264	99	103	5	23	20	50
Total	1394	632	731	39	263	224	257

4.7. Summary: Contribution from All Sources

Based on the inventory of sources discussed in this chapter, a summary of the contribution by the different nonpoint sources to direct annual fecal coliform loading to the streams is given in Table 4.17. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 4.17.

From Table 4.17, it is clear that nonpoint source loadings to the land surface are 500 times larger than direct loadings to the streams (not including commercial sources), with pastures receiving about 98% of the total fecal coliform load. It could be prematurely assumed that most of the fecal coliform loading in streams originates from upland sources, primarily from pastures. However, other factors such as precipitation amount and pattern, manure application activities (time and method), type of waste (solid versus liquid manure) and proximity to streams also impact the amount of fecal coliform from upland areas that reaches the streams. The HSPF model considers these factors when estimating fecal coliform loads to the receiving waters, as described in Chapter 5.

Table 4.17. Annual fecal coliform loadings to the stream and the various land use categories in the Linville Creek watershed.

Source	Fecal coliform loading ($x10^{12}$ cfu/year)	Percent of total loading
Direct loading to streams		
Cattle in stream	98.5	0.2%
Wildlife in stream	0.7	<0.1%
Straight pipes	12.0	<0.1%
Loading to land surfaces		
Cropland	4.3	<0.1%
Pasture 1	44738	80.3%
Pasture 2	5157	9.3%
Pasture 3	4759	8.5%
Residential[a]	932	1.7%
Forest	12.8	<0.1%
Total	55714.3	

[a] Includes loads received from both High and Low Density Residential and Farmstead due to failed septic systems and pets.

CHAPTER 5: MODELING PROCESS FOR FECAL COLIFORM TMDL DEVELOPMENT

A key component in developing a TMDL is establishing the relationship between pollutant loadings (both point and nonpoint) and in-stream water quality conditions. Once this relationship is developed, management options for reducing pollutant loadings to streams can be assessed. In developing a TMDL, it is critical to understand the processes that affect the fate and transport of the pollutants and cause the impairment of the waterbody of concern. Pollutant transport to water bodies is evaluated using a variety of tools, including monitoring, geographic information systems (GIS), and computer simulation models. In this chapter, modeling process, input data requirements, model calibration procedure and results, and model validation results are discussed.

5.1. Model Description

The TMDL development requires the use of a watershed-based model that integrates both point and nonpoint sources and simulates in-stream water quality processes. The Hydrologic Simulation Program – FORTRAN, Windows Version (HSPF) (Duda *et al*., 2001) was used to model fecal coliform transport and fate in the Linville Creek watershed. Specifically, the windows interface within the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) System provides pre- and post-processing support for HSPF. The ArcGIS 8.0 GIS program was used to display and analyze landscape information for the development of input for HSPF.

The HSPF model simulates nonpoint source runoff and pollutant loadings, performs flow routing through streams, and simulates in-stream water quality processes (Duda *et al*., 2001). HSPF estimates runoff from both pervious and impervious parts of the watershed and stream flow in the channel network. The sub-module PWATER within the module PERLND simulates runoff, and hence, estimates the water budget on pervious areas (e.g., agricultural land). Runoff from largely impervious areas is modeled using the IWATER sub-module within the IMPLND module. The simulation of flow through the stream network is performed using the sub-modules, HYDR and ADCALC within the module RCHRES. While HYDR routes the water through the stream network, ADCALC calculates variables used for simulating convective transport of the pollutant in the stream. Fate of fecal coliform on pervious and impervious land segments is simulated using the PQUAL (PERLND module) and IQUAL (IMPLND module) sub-modules, respectively. Fate of fecal coliform in stream water is simulated using the GQUAL sub-module within RCHRES module. Fecal coliform bacteria are simulated as a dissolved pollutant using the general constituent pollutant model (GQUAL) in HSPF.

5.2. Selection of Sub-watersheds

Linville Creek is a moderately sized watershed (29,647 ac) and the model framework selected is suitable for this size. To account for the spatial distribution of fecal coliform sources, the watershed was divided into eleven sub-watersheds as shown in Figure 3.1. Tributaries to the impaired segment (Linville Creek B46-1,2,5,7,8,11) include Daphna Creek (B46-03), Joes Creek (B46-06), West Fork Linville Creek (B46-10), Tide Spring Branch (B46-04), and an unnamed tributary (B46-09). The stream network was delineated based on the blue line stream network from USGS topographic maps with each sub-watershed having at least one stream segment. Because loadings of fecal coliform are believed to be associated with land use activities and the degree of development in the watershed, sub-watersheds were chosen based on uniformity of land use. The sub-watersheds B46-07 and B46-08 were delineated to preserve the stream network of the watershed and result in much smaller sub-watersheds relative to the other sub-watersheds.

5.3. Input Data Requirements

The HSPF model requires a wide variety of input data to describe hydrology, water quality, and land use characteristics of the watershed. The different types and sources of input data used to develop the TMDL for the Linville Creek watershed are discussed below.

5.3.1. Climatological Data

Weather data needed to conduct simulations were obtained from the weather station closest to the watershed. Hourly precipitation data were obtained from the National Climatic Data Center's (NCDC) cooperative weather station at Dale Enterprise, located just outside the headwaters of the Linville Creek watershed. Because hourly data for other meteorological parameters, such as solar radiation and temperature, were not available at Dale Enterprise, daily measured or simulated data from Monterey (Virginia), Lynchburg Airport (Virginia), and Elkins Airport (West Virginia) were used to complete the meteorological data set required for running HSPF.

Missing hourly precipitation data were filled in by disaggregating daily precipitation data from Dale Enterprise using the hourly precipitation distribution from the Staunton Sewage Treatment Plant as the template data set. Daily precipitation data from Timberville were used to verify daily precipitation data from Dale Enterprise. Detailed descriptions of the weather data and the procedure for converting the raw data into the required data set are described in Appendix D.

5.3.2. Hydrology Model Parameters

The hydrology parameters required by PWATER and IWATER were defined for every land use category for each sub-watershed. For each reach, a function table (FTABLE) is required to describe the relationship between water depth, surface area, volume, and discharge (Duda *et al*., 2001). These parameters were estimated by surveying representative channel cross-sections in each sub-watershed. Information on stream geometry in each sub-watershed is presented in Table 5.1. Hydrology parameters required for the PWATER, IWATER, and HYDR ADCALC sub-modules are listed in HSPF Version 11 User's Manual (Bicknell *et al*., 1997). Parameters required as inputs for PQUAL, IQUAL, and GQUAL are given in the HSPF User's Manual (Bicknell *et al*., 1997). Runoff estimated by the model is also an input to the water quality components. Values for the parameters were estimated based on local conditions when possible; otherwise the default parameters provided within HSPF were used.

Table 5.1. Stream Characteristics of the Linville Creek Watershed.

Sub-watershed	Stream length (mile)	Average width (ft)	Average channel depth (ft)	Slope (ft/ft)
B46-01	1.362	21	12	0.0008
B46-02	3.192	18	9	0.0057
B46-03	4.505	8	3	0.0057
B46-04	3.923	6	2	0.0006
B46-05	2.839	13	7	0.0009
B46-06	7.062	5	3	0.0023
B46-07	0.919	9	5	0.0023
B46-08	0.924	5	5	0.0023
B46-09	2.232	7	2	0.0075
B46-10	5.478	7	3	0.0021
B46-11	5.089	7	3	0.0023

5.4. Land Use

Using 1997 aerial photographs, VADCR identified 26 land use types in the watershed. In May and September of 2002, Virginia Tech personnel verified these land uses. The 26 land use types were consolidated into nine categories based on similarities in hydrologic and waste application/production features (Table 5.2). These categories were assigned pervious and impervious percentages, which allowed a land use with both pervious and impervious fractions to be modeled using both the PERLND and IMPLND modules in HSPF. Land use data were used to select several hydrology and water quality parameters for the simulations. Land use distribution in the eleven sub-watersheds as well as in the entire Linville Creek watershed is presented in Table 5.3.

Table 5.2. Consolidation of VADCR land use categories for Linville Creek watershed.

TMDL Land Use Categories	Pervious/Impervious[a] (Percentage)	VADCR Land Use Categories (Class No.)
Cropland	Pervious (100%)	Row Crops (2110) Gullied Row Crops (2111) Row Crops Stripped (2113) Rotational Hay (2114) Orchard (221)
Pasture 1	Pervious (100%)	Improved Pasture/Hayland (2122) Pasture (2121)
Pasture 2	Pervious (100%)	Unimproved Pasture (2123) Grazed Woodland (43)
Pasture 3	Pervious (100%)	Overgrazed Pasture (2124)
Farmstead	Pervious (72%) Impervious (28%)	Housed Poultry (2321) Farmstead (13) Farmstead with Dairy Waste Facility (813) Large Individual Dairy Waste Facility (8)
Rural Residential	Pervious (72%) Impervious (28%)	Built-Up > 50% Porous (12) Rural Residential (14) Wooded Residential (44)
Urban Residential	Pervious (75%) Impervious (25%)	Built-Up < 50% Porous (11) Unclassified (999) Transitional and Disturbed Sites (7)
Loafing Lot	Pervious (100%)	Dairy Loafing Lots(2312) Unhoused Poultry (2322)
Forest	Pervious (100%)	Forest (40) Unmanaged Grass and Shrubs (3) Water (5) Nurseries and Christmas Tree Farms (222)

[a] Percent perviousness/imperviousness information was used in modeling (described in Section 5.4)

Table 5.3. Land use distribution in the Linville Creek watershed (acres).

Landuse	Sub-watersheds											Total
	B46-01	B46-02	B46-03	B46-04	B46-05	B46-06	B46-07	B46-08	B46-09	B46-10	B46-11	
Cropland	38.7	1054.5	134.7	247.5	811.3	534.9	116.5	133	220.5	1722.7	1320.9	6335.2
Pasture 1	161.7	835.2	832.1	448.8	1720.4	1313.3	19	89	580.8	968.9	1226.9	8196.1
Pasture 2	3.9	90.3	189.1	131.6	249.7	190.6	0.6	1	161.3	237.7	538.7	1794.5
Pasture 3	31.6	203.1	869.9	193.5	804.7	614.3	0	12.3	64.5	621.6	1226.9	4642.4
Farmstead	13.8	154.7	97	71.3	167.3	164.5	18.2	19.3	30	210.7	247.5	1194.3
Rural Residential	119.2	57	344.9	62	136.4	263	5	47.3	311.7	178	310.9	1835.4
Urban Residential	515.5	10.8	111.2	7.5	12.5	14.9	2.1	0	27.4	30.6	84.7	817.2
Loafing Lot	0	8.8	0	8.6	0	49.8	0	0	29.9	20.4	46.5	164
Forest	6.4	135.5	225.3	385.1	435.9	1465.8	7.6	7.9	365.8	1024.1	608.1	4667.5
Total	890.8	2549.9	2804.2	1555.9	4338.2	4611.1	169	309.8	1791.9	5014.7	5611.1	29646.6

5.5. Accounting for Pollutant Sources

5.5.1. Overview

There were 34 VADEQ permitted fecal coliform point sources in the Linville Creek watershed. Of the 34 permitted sources, 33 of them were general permits for facilities/residences discharging at or less than 1000 gallons per day (Table 4.3). The remaining permitted discharge for fecal coliform was allowed to discharge 0.03 million gallons per day at site VA0085588 (Table 4.2).

Fecal coliform loads that are directly deposited by cattle and wildlife in streams were treated as direct nonpoint sources in the model. Fecal coliform that is land-applied or deposited on land was treated as nonpoint source loading; all or part of that load may be transported to the stream as a result of surface runoff during rainfall events. Direct nonpoint source loading was applied to the stream reach in each sub-watershed as appropriate. The point sources permitted to discharge fecal coliform in the watershed were incorporated into the simulations at the stream locations designated in the permit.

The nonpoint source loading was applied in the form of fecal coliform counts to each land use category in a sub-watershed on a monthly basis. Fecal coliform die-off was simulated while manure was being stored, while it was on the land, and when it was deposited in streams. Both direct nonpoint and nonpoint source loadings were varied by month to account for seasonal differences such as cattle and wildlife access to streams.

We developed a spreadsheet program internally and used it to generate the nonpoint source fecal coliform inputs to the HSPF model. This spreadsheet program takes inputs of animal numbers, land use, and management practices by sub-watershed and outputs hourly direct deposition to streams and monthly loads to each land use type. We customized the program to allow direct deposition in the stream by dairy cows, ducks, and geese to occur only during daylight hours. The spreadsheet program calculates the manure produced in confinement by each animal type (dairy cows, beef cattle, and poultry) and distributes this manure to available lands (crops and pasture) within each sub-watershed. If a sub-watershed does not have sufficient land to apply all the manure its animals generate, the excess manure is distributed equally to other sub-watersheds that have land that has not yet received manure. In Linville Creek, however, there was sufficient land available in each sub-watershed such that all manure generated within a sub-watershed could be applied in the same sub-watershed.

5.5.2. Modeling fecal coliform die-off

Fecal coliform die-off was modeled using a first order die-off equation of the form:

$$C_t = C_0 10^{-Kt} \qquad [5.1]$$

where: C_t = concentration or load at time t,

C_0 = starting concentration or load,

K = decay rate (day^{-1}),

and t = time in days.

A review of literature provided estimates of decay rates that could be applied to waste storage and handling in the Linville Creek watershed (Table 5.4).

Table 5.4. First order decay rates for different animal waste storage as affected by storage/application conditions and their sources.

Waste type	Storage/application	Decay rate (day^{-1})	Reference
Dairy manure	Pile (not covered)	0.066	Jones (1971)[a]
	Pile (covered)	0.028	
Beef manure	Anaerobic lagoon	0.375	Coles (1973)[a]
Poultry litter	Soil surface	0.035	Giddens *et al*. (1973)
		0.342	Crane *et al*. (1980)

[a] Cited in Crane and Moore (1986)

Based on the values cited in the literature, the following decay rates were used in simulating fecal coliform die-off in stored waste.

- Liquid dairy manure: Because the decay rate for liquid dairy manure storage could not be found in the literature, the decay rate for beef manure in anaerobic lagoons (0.375 day^{-1}) was used.

- Solid cattle manure: Based on the range of decay rates (0.028-0.066 day^{-1}) reported for solid dairy manure, a decay rate of 0.05 day^{-1} was used assuming that a majority of manure piles are not covered.

- Poultry waste in pile/house: Because no decay rates were found for poultry waste in storage, a decay rate of 0.035 day^{-1} was used based on the lower decay rate reported for poultry litter applied to the soil surface. The lower value was used instead of the higher value of 0.342 day^{-1} (Table 5.4) because fecal coliform die-off in storage was assumed to be lower, given the absence of UV radiation and predation by soil microbes.

The procedure for calculating fecal coliform counts in waste at the time of land application is included in Appendix C. Depending on the duration of storage, type of storage, type of manure, and die-off factor, the fraction of fecal coliform surviving in the manure at the end of storage is calculated. While calculating survival fraction at the end of the storage period, the daily addition of manure and coliform die-off of each fresh manure addition is considered to arrive at an effective survival fraction over the entire storage period. By multiplying the survival fraction with total fecal coliform produced per year (in as-excreted manure), the amount of fecal coliform available for application to land per year is estimated. Monthly fecal coliform application to land is estimated by multiplying the amount of fecal coliform available for application to land per year by the fraction of manure applied to land during that month. A decay rate of 0.045 day^{-1} was assumed for fecal coliform on the land surface. The decay rate of 0.045 day^{-1} is represented in HSPF by specifying a maximum surface buildup of nine times the daily loading rate. An in-stream decay rate of 1.15 day^{-1} (USEPA, 1985) was used.

5.5.3. Modeling Nonpoint Sources

For modeling purposes, nonpoint fecal coliform loads were those that were deposited or applied to land and, hence, required surface runoff events for transport to streams. Fecal coliform loading by land use for all sources in each sub-watershed is presented in Chapter 4. The existing condition fecal coliform loads are based on best estimates of existing wildlife, livestock, and human populations and fecal coliform production rates. Fecal coliform in stored waste was adjusted for die-off prior to the time of land application when calculating loadings to cropland and pasture. For a given period of storage, the total amount of fecal coliform present in the stored manure was adjusted for die-off on a daily basis. Fecal coliform loadings to each sub-watershed in the Linville Creek watershed are presented in Appendix E. The sources of fecal coliform to different land use categories and how the model handled them are briefly discussed below.

1. Cropland: Liquid dairy manure and solid manure are applied to cropland as described in Chapter 4. Fecal coliform loadings to cropland were adjusted to account for die-off during storage and partial incorporation during land-application. Wildlife contributions were also added to the cropland areas. For modeling, monthly fecal coliform loading assigned to cropland was distributed over the entire cropland acreage within a sub-watershed. Thus, loading rate varied by month and sub-watershed.

2. Pasture: In addition to direct deposition from livestock and wildlife, pastures receive applications of liquid dairy manure and solid manure as described in Chapter 4. Applied fecal coliform loading to pasture was reduced to account for die-off during storage. For modeling, monthly fecal coliform loading assigned to pasture was distributed over the entire pasture acreage within a sub-watershed.

3. Loafing Lot: Loafing lots receive manure deposited by cows during the time they spend on the loafing lots (Table 4.8, Table 4.9). Fecal coliform loads resulting from direct waste deposition by cows in a particular sub-watershed are distributed uniformly over the entire loafing lot acreage in each sub-watershed.

4. Low Density Residential and Farmstead: Fecal coliform loading on rural residential and Farmstead land use came from failing septic systems, wildlife and waste from pets. In the model simulations, fecal coliform loads produced by failing septic systems and pets in a sub-watershed were combined and assumed to be uniformly applied to the low density residential land use areas.

5. High-Density Residential: The high density residential contained much of the Commercial/Industrial areas. Fecal coliform loading to the high density residential land use was assumed to be a constant 10.3 x 10^6 cfu/day/acre (USEPA, 2000)

6. Forest: Wildlife not defecating in streams, cropland, and pastures provided fecal coliform loading to the forested land use. Fecal coliform from wildlife in forests was applied uniformly over the forest areas.

5.5.4. Modeling Direct Nonpoint Sources

Fecal coliform loads from direct nonpoint sources included cattle in streams, wildlife in streams, and direct loading to streams from straight pipes from residences. Also, contributions of fecal coliform from interflow and groundwater were modeled as having a constant concentration of 15 cfu/100mL for interflow and 7.5 cfu/100mL for groundwater. Loads from direct nonpoint sources in each sub-watershed are described in detail in Chapter 4.

5.6. Model Calibration and Validation

Model calibration is the process of selecting model parameters that provide an accurate representation of the watershed. Validation ensures that the calibrated parameters are appropriate for time periods other than the calibration period. In this section, the procedures followed for calibrating the hydrology and water quality components of the HSPF model are discussed. The calibration and validation results of the hydrology component and the calibration results of the water quality component are presented.

5.6.1. Hydrology

For the hydrologic component of the HSPF calibration, observed values for daily stream flow are required. Flow data from the USGS station monitoring Linville Creek located near Broadway, Virginia (Station Number 01632082) were used to calibrate HSPF. The drainage area monitored at the station is 45.5 square miles (29,120 acres) and the current available period of record is August 1985 through September 2001 (approximately 16 years). The calibration period selected was September 1987 to December 1992 (64 months), and the validation period was January 1993 to September 2001 (105 months).

The calibration of the HSPF hydrology parameters resulted in simulated flows that accurately matched the observed data for Linville Creek. A comparison of the simulated and observed stream flow data is given in Table 5.5 for the calibration period of September 1987 to December 1992 for Linville Creek. There was very good agreement between the observed and simulated stream flow indicating that the model represented the hydrologic characteristics of the watershed very well. In Figure 5.1, the simulated and observed stream flow for the calibration period is shown. The simulated data follow the pattern of the observed data very well. The model closely simulates both low flows and storm peaks.

Table 5.5. Linville Creek calibration simulation results (September 1987 to December 1993).

Parameter	Observed (inches)	Simulated (inches)	Percent Error
Annual total stream flow	9.6	8.9	-7.3%
Annual summer[a] stream flow	1.4	1.2	-14%
Annual winter[b] stream flow	2.9	2.8	-3%

[a] June – August

[b] December – February

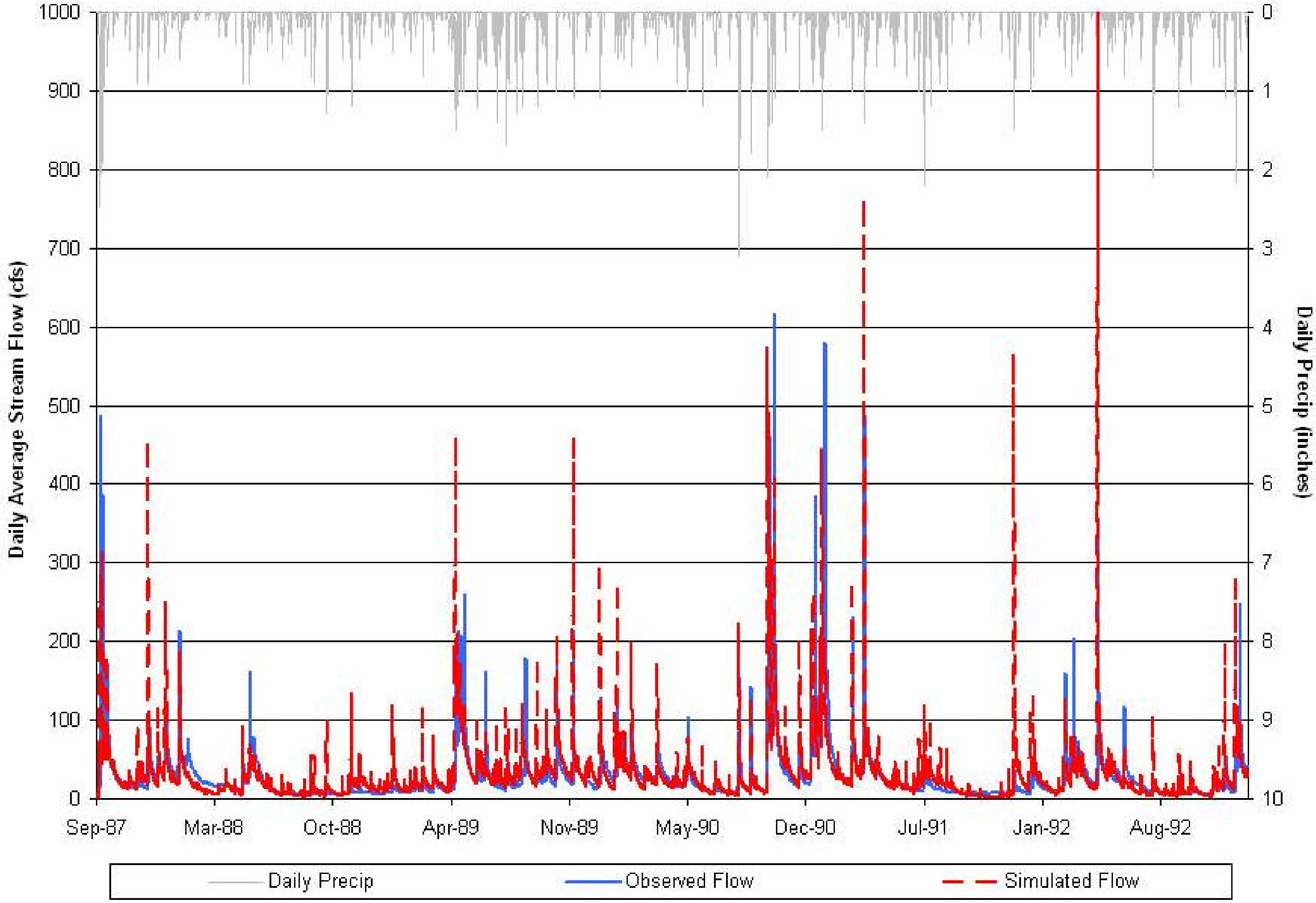


Figure 5.1. Simulated and observed stream flow for Linville Creek for the calibration period (Sept. 1987 to Dec. 1993).

The calibrated data set was then used in the model to predict runoff for a different time period for Linville Creek (January 1993 through September 2001) to provide a basis for evaluating the appropriateness of the calibrated parameters. A comparison of the simulated and observed stream flow data is given in Table 5.6 for the validation period of January 1993 to September 2001 for Linville Creek.

Table 5.6. Linville Creek validation simulation results (January 1993 to September 2001).

Parameter	Simulated (inches)	Observed (inches)	Percent Error
Annual total stream flow	13.5	12.7	6.3%
Annual summer[a] stream flow	2.2	2.1	4.8%
Annaual winter[b] stream flow	4.3	4.0	7.5%

[a] June – August

[b] December – February

There was very good agreement between the observed and simulated stream flow, indicating that the calibrated parameters represent the characteristics of the watershed reasonably well for time periods outside the calibration period. The simulated and observed stream flow for the validation period is shown in Figure 5.2. The simulated data follow the pattern of the observed data and the validation results indicate that the calibrated model characterizes the hydrologic processes of the Linville Creek watershed.

The pathway that water takes to reach the stream is extremely important when simulating fecal coliform. The HSPF model considers three pathways that water from precipitation falling on the land surface can follow to reach the stream. These pathways are surface flow, interflow or shallow subsurface flow, and active groundwater flow. The main pathway fecal coliform can follow to reach the stream, besides point sources and direct deposited nonpoint sources, is surface flow. Therefore, the partition of total flow among surface flow (SURO), interflow

(IFWO), and active groundwater (AGWO) is very important. The partitioning of flow among the three pathways was investigated for the Linville Creek simulations. The portion of the total flow among the three pathways is given in Table 5.7. Based on our experience monitoring and modeling other watersheds near the Linville Creek watershed, the partitioning of flow among the three pathways is acceptable.

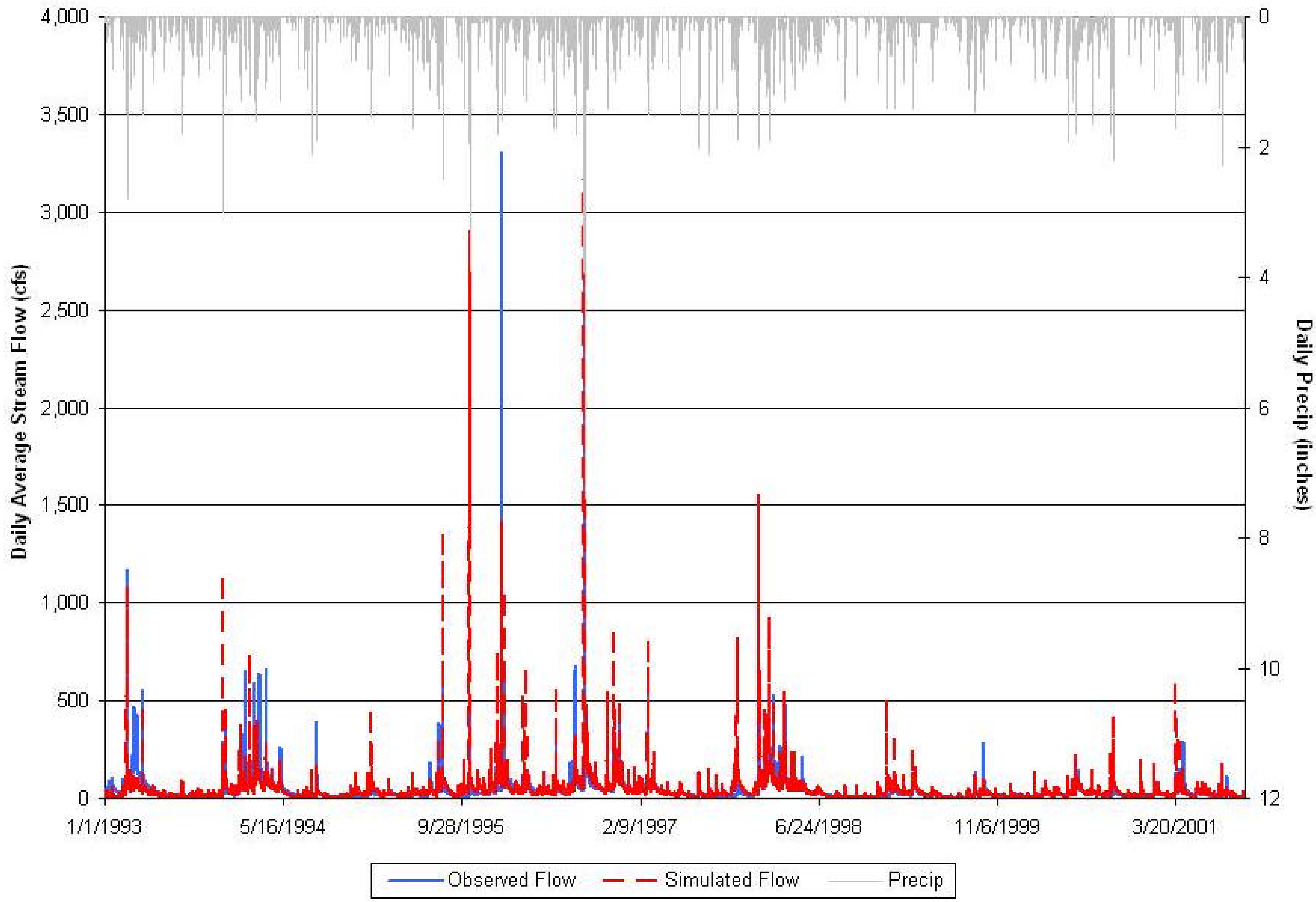


Figure 5.2. Simulated and observed average daily stream flow for Linville Creek for the validation period (January 1993 to September 2001).

Table 5.7. Partition of flow among surface flow, interflow, and groundwater flow for the January 1993 to September 2001 validation period.

Flow Path	Simulated (inches)	Percent of Flow
Total Runoff	13.5	---
Baseflow	7.4	55%
Interflow	2.0	15%
Surface Flow	4.1	30%

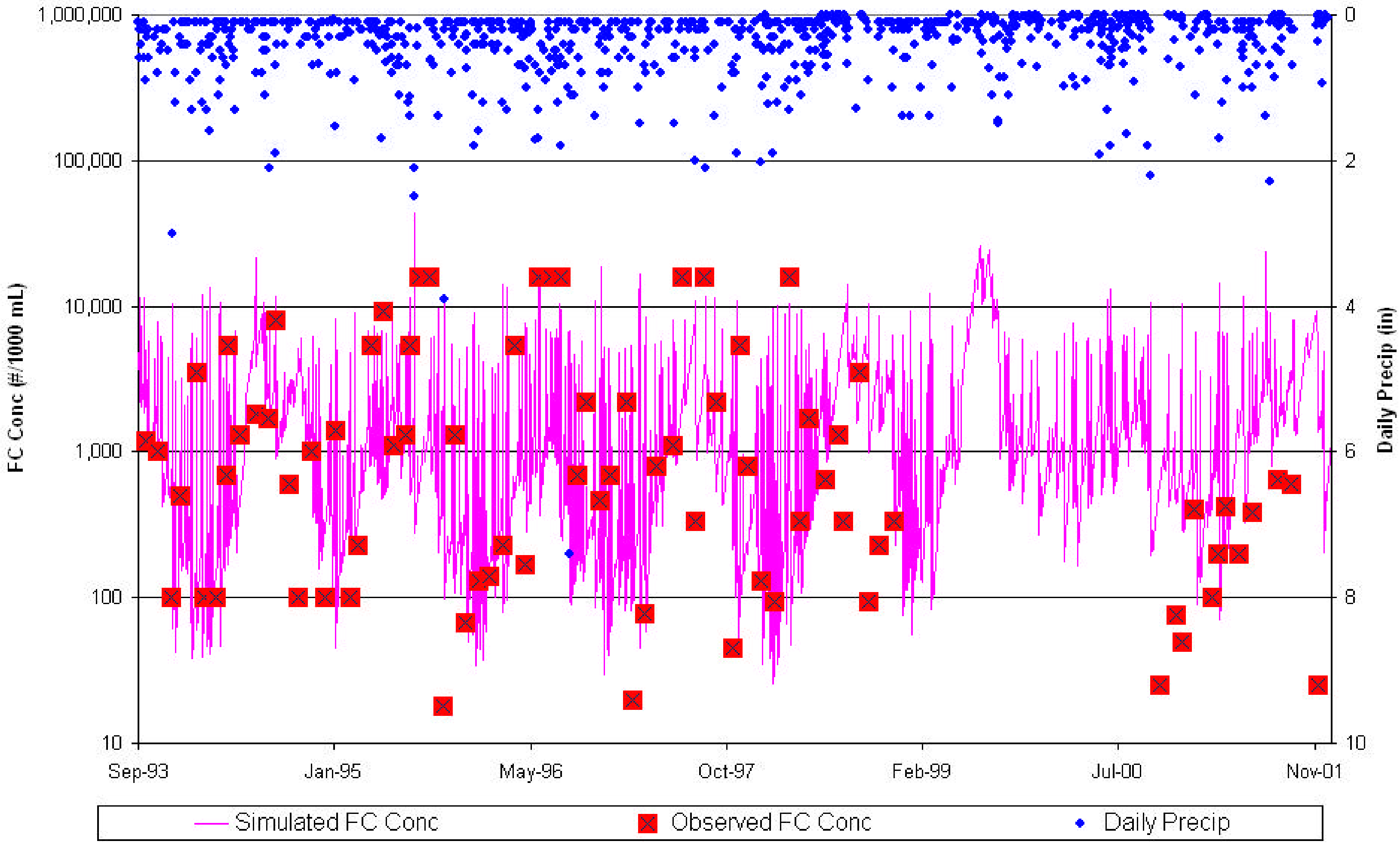
5.6.2. Fecal coliform calibration

The water quality component of HSPF was calibrated using eighty-one fecal coliform samples for the Linville Creek watershed that were collected by VADEQ from November 1993 to September 2001. The accuracy of the simulations was assessed visually using graphs of simulated and observed values.

<u>Results</u>

There was generally good agreement among the simulated and observed fecal coliform concentrations. The daily average of the simulated concentrations and the observed fecal coliform concentration are shown in Figure 5.3. A logarithmic scale is used on the left axis for the fecal coliform concentrations in Figure 5.3. The right-axis represents precipitation values (the blue diamonds) and has a linear scale. The overall pattern of the observed concentrations is represented in the simulated concentrations. For instance, simulated concentrations match the low concentrations observed during winter periods. Also, the simulated concentrations increased during the summer and early fall, during which time the observed higher concentrations generally occurred. Simulated concentrations were not as low as some of the observed concentrations. Efforts were made to improve the agreement between the simulated and observed concentrations by adjusting the input to the model and investigating if there were errors or misrepresentations in the precipitation data to no avail. In general, the agreement between the simulated and observed concentrations was good and the model represents the processes influencing the concentration of fecal coliform in Linville Creek well.

The pollutant transport and water quality input parameters used in the simulation of Linville Creek are listed in Table 5.8. The parameters for the PQUAL, IQUAL, and the GQUAL modules of HSPF are given in Table 5.8 along with an explanation of the value and the ranges for the parameters.



1,000,000
100,000
10,000
1,000
100
10
FC Conc (#/1000 mL)
0
2
4
6
8
10
Daily Precip (in)
Sep-93
Jan-95
May-96
Oct-97
Feb-99
Jul-00
Nov-01
Simulated FC Conc
Observed FC Conc
Daily Precip

Figure 5.3. Linville Creek fecal coliform calibration for existing conditions.

Table 5.8. Input parameters used in HSPF simulations for Linville Creek.

Parameter	Definition	Units	RANGE OF VALUES				START	FINAL CALIB.	FUNCTION OF…
			TYPICAL		POSSIBLE				
			MIN	MAX	MIN	MAX			
PERLND									
PWAT-PARM2									
FOREST	Fraction forest cover	none	0.00	0.5	0	0.95	0.0, 1.0	1.0 forest, 0.0 other	Forest cover
LZSN	Lower zone nominal soil moisture storage	inches	3	8	2	15	14.1	5-13[1]	Soil properties
INFILT	Index to infiltration capacity	in/hr	0.01	0.25	0.001	0.5	0.16	0.03-0.08[1]	Soil and cover conditions
LSUR	Length of overland flow	feet	200	500	100	700	300	238-246[1]	Topography
SLSUR	Slope of overland flowplane	none	0.01	0.15	0.001	0.3	0.035	0.02-0.04[1]	Topography
KVARY	Groundwater recession variable	1/in	0	3	0	5	0	0	Calibrate
AGWRC	Base groundwater recession	none	0.92	0.99	0.85	0.999	0.98	0.93-0.98[1]	Calibrate
PWAT-PARM3									
PETMAX	Temp below which ET is reduced	deg. F	35	45	32	48	40	40	Climate, vegetation
PETMIN	Temp below which ET is set to zero	deg. F	30	35	30	40	35	35	Climate, vegetation
INFEXP	Exponent in infiltration equation	none	2	2	1	3	2	2	Soil properties
INFILD	Ratio of max/mean infiltration capacities	none	2	2	1	3	2	2	Soil properties
DEEPFR	Fraction of GW inflow to deep recharge	none	0	0.2	0	0.5	0.1	0.10	Geology
BASETP	Fraction of remaining ET from baseflow	none	0	0.05	0	0.2	0.02	0	Riparian vegetation
AGWETP	Fraction of remaining ET from active GW	none	0	0.05	0	0.2	0	0	Marsh/wetland s ET
PWAT-PARM4									
CEPSC	Interception storage capacity	inches	0.03	0.2	0.01	0.4	0.1	monthly[1]	Vegetation
UZSN	Upper zone nominal soil moisture storage	inches	0.10	1	0.05	2	1.128	Monthly[1]	Soil properties
NSUR	Mannings' n (roughness)	none	0.15	0.35	0.1	0.5	0.2	0.2-0.45[1]	Land use, surface condition
INTFW	Interflow/surface runoff partition parameter	none	1	3	1	10	0.75	0.8-1.0[1]	Soils, topography, land use
IRC	Interflow recession parameter	none	0.5	0.7	0.3	0.85	0.5	0.63-0.7[1]	Soils, topography, land use
LZETP	Lower zone ET parameter	none	0.2	0.7	0.1	0.9	monthly	monthly[1]	Vegetation
QUAL-INPUT									
ACQOP	Rate of accumulation of constituent	#/day	[2]	[2]	[2]	[2]	[2]	monthly[1]	Land use
SQOLIM	Maximum accumulation of constituent	#	[2]	[2]	[2]	[2]	[2]	9 x ACQOP	Land use
WSQOP	Wash-off rate	in/hr	[2]	[2]	[2]	[2]	[2]	2.5	Land use
IOQC	Constituent conc. in interflow	#/ft3	[2]	[2]	[2]	[2]	[2]	4248	Land use

[1] Varies with land use

[2] Typical ranges not given by HSPF guidance

Table 5.8. Input parameters used in HSPF simulations for Linville Creek. (Continued)

Parameter	Definition	Units	RANGE OF VALUES				START	FINAL CALIB.	FUNCTION OF…
			TYPICAL		POSSIBLE				
			MIN	MAX	MIN	MAX			
PERLND									
AOQC	Constituent conc. in active groundwater	#/ft3	[2]	[2]	[2]	[2]		2124	Land use
IMPLND									
IWAT-PARM2									
LSUR	Length of overland flow	feet	200	500	100	700	300	250	Topography
SLSUR	Slope of overland flowplane	none	0.01	0.15	0.001	0.3	0.035	0.01	Topography
NSUR	Mannings' n (roughness)	none	0.15	0.35	0.1	0.5	0.2	0.10	Land use, surface condition
RETSC	Retention/interception storage capacity	inches	0.03	0.2	0.01	0.4	0.1	0.125	Land use, surface condition
IWAT-PARM3									
PETMAX	Temp below which ET is reduced	deg. F	35	45	32	48	40	40	Climate, vegetation
PETMIN	Temp below which ET is set to zero	deg. F	30	35	30	40	35	35	Climate, vegetation
IQUAL									
ACQOP	Rate of accumulation of constituent	#/day	[2]	[2]	[2]	[2]	[2]	1.0E+07	Land use
SQOLIM	Maximum accumulation of constituent	#	[2]	[2]	[2]	[2]	[2]	3.0E+07	Land use
WSQOP	Wash-off rate	in/hr	[2]	[2]	[2]	[2]	[2]	1.5	Land use
RCHRES									
HYDR-PARM2									
KS	Weighting factor for hydraulic routing		[2]	[2]	[2]	[2]	[2]	0.3	
GQUAL									
FSTDEC	First order decay rate of the constituent	1/day	[2]	[2]	[2]	[2]	[2]	1.15	
THFST	Temperature correction coeff. for FSTDEC		[2]	[2]	[2]	[2]	[2]	1.05	

[1] Varies with land use
[2] Typical ranges not given by HSPF guidance

CHAPTER 6: BENTHIC STRESSOR ANALYSIS

6.1. Introduction

TMDLs must be developed for a specific pollutant. Because a benthic impairment is based on a biological inventory, rather than on physical or chemical water quality parameters, the pollutant is not implicitly identified in the assessment, as it is with physical or chemical impairments. The process outlined in USEPA's *Stressor Identification Guidance Document* (USEPA, 2000) was used to identify the critical stressor for Linville Creek. A list of candidate causes was developed from published literature and stakeholder input. Chemical and physical monitoring data provided additional evidence to support or eliminate the potential candidate causes. Logical pathways were explored between observed characteristics of the benthic community, potential stressors, and intermediate steps or interactions that would be consistent in establishing a cause and effect relationship with each candidate cause. The common candidate benthic stressors are suspended solids, temperature, pH, toxics, organic matter, nutrients, and sediment. Each of these is considered in the following sections.

6.2. Eliminated Stressors

<u>Suspended Solids</u>

Total suspended solids (TSS) data (Figure 6.1) and turbidity data (Figure 6.2) indicate predominantly low levels within normal ranges, with infrequent spikes. The periodic spikes were not deemed sufficient to cause the impairment.

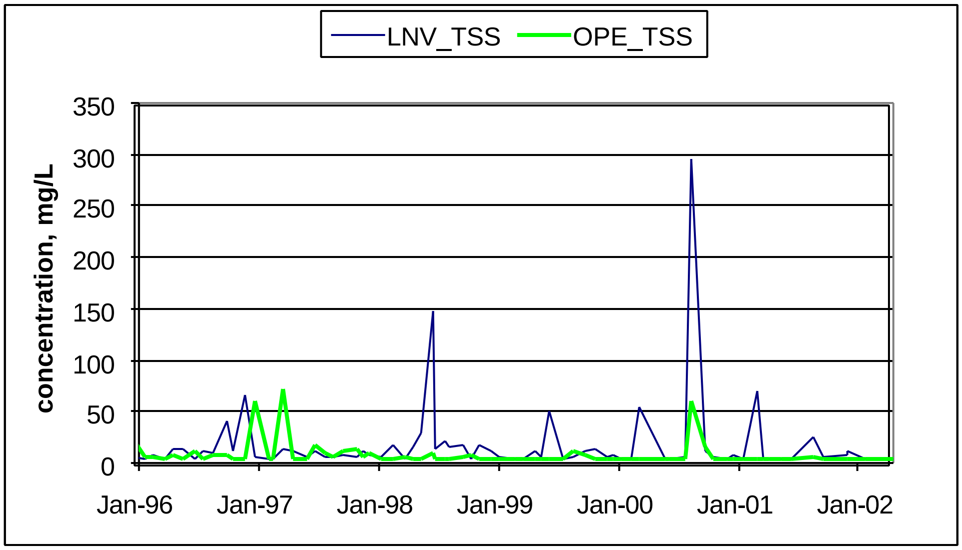


Figure 6.1. Suspended Solids Concentration in Linville and Upper Opequon Creeks.

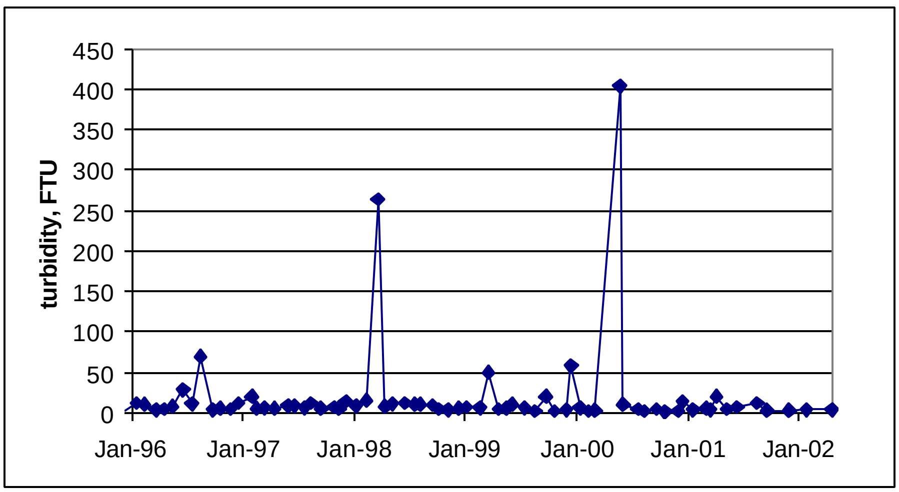


Figure 6.2. Turbidity Data for Linville Creek

Temperature

Although the habitat evaluation indicated sparse riparian vegetation, the water temperature appears to fluctuate within normal bounds during the 8 years of monitored data. The stream temperature never exceeded the maximum allowable temperature standard of 31^{o}C for Class IV waters, as shown in Figure 6.3. Therefore, temperature does not appear to be a stressor.

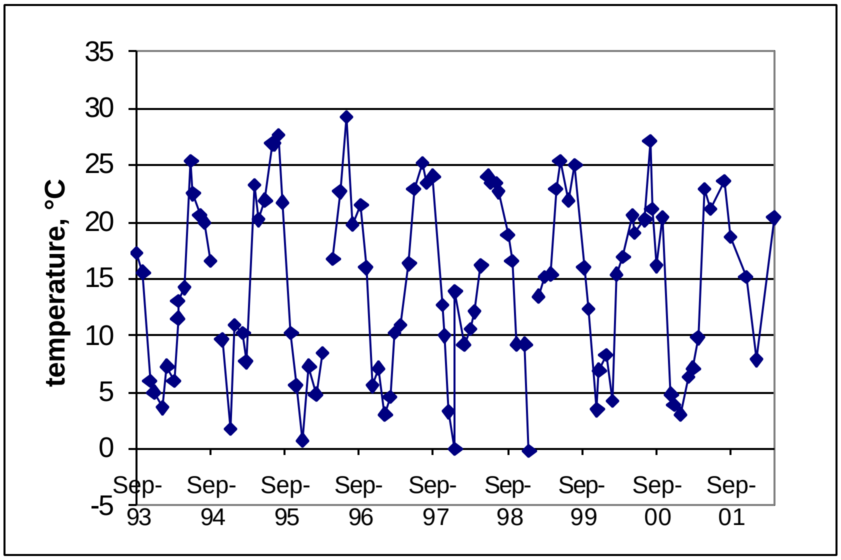


Figure 6.3. Water Temperature in Linville Creek.

pH

All field measurements of in-stream pH values fall between the standard limits of 6.5 – 9.5 for Class IV waters, as shown in Figure 6.4. Alkalinity concentrations also appear fairly constant, and within the normal range of 30 – 500 mg/L for groundwater in the Valley and Ridge physiographic region as shown in Figure 6.5. Therefore, pH is not considered to be a stressor.

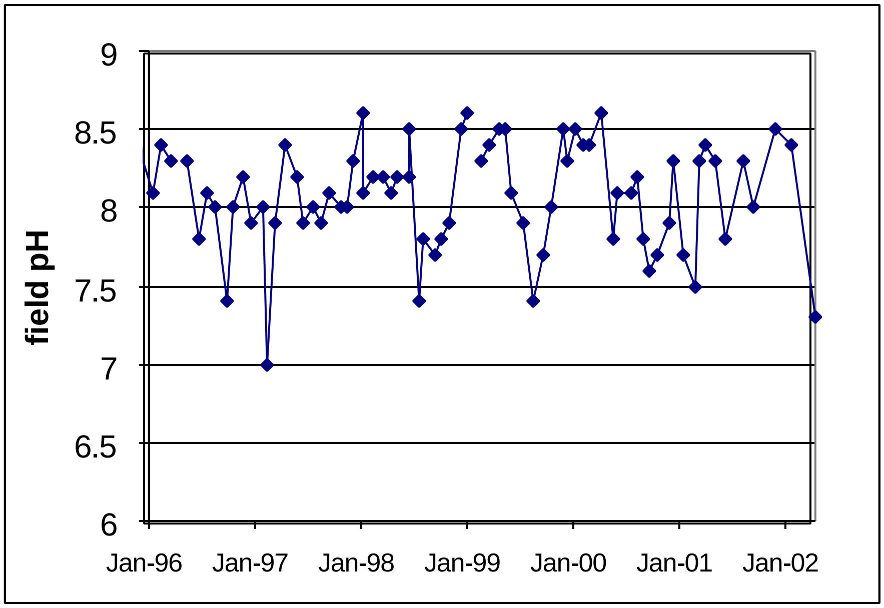


Figure 6.4. Field pH Data for Linville Creek Samples.

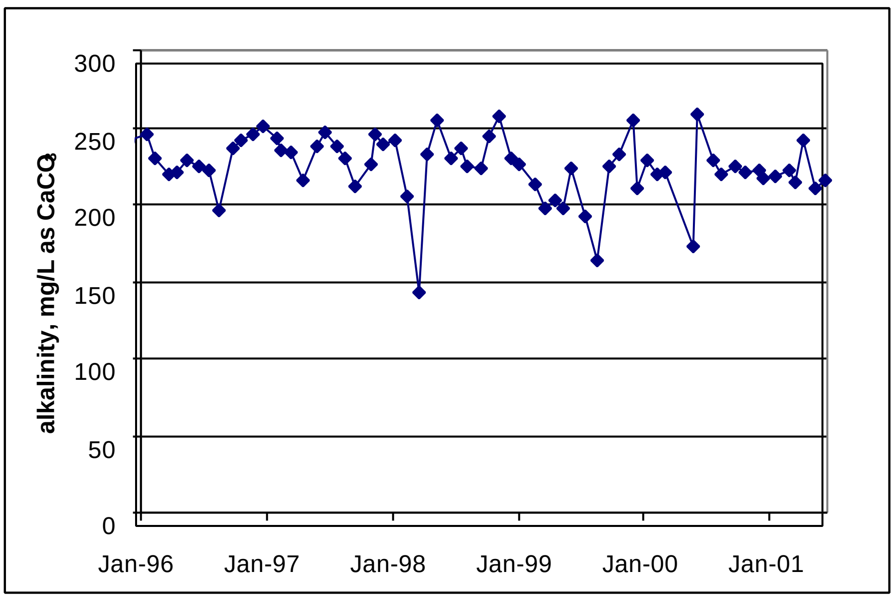


Figure 6.5. Alkalinity Concentration in Linville Creek.

Toxics

No violations of USEPA's chronic aquatic life criteria have been recorded. No violation of the National Oceanic and Atmospheric Administration's (NOAA's) sediment “Effects Range – Median” (ERM) values have been recorded. These ERM values were determined as the lower 50% range of monitored data, with consideration of levels at which adverse effects were noted; thus, violation of the ERM value is likely to cause adverse effects on aquatic life. The relatively low number of shredders in Linville Creek could be the result of the presence of toxics, but is most probably the result of excessive sediment and a lack of leaf input due to reduced tree canopy in the riparian zones. In a 1999 county household water quality study, no samples had concentrations of toxics that exceeded the EPA health advisory levels or the maximum contaminant levels. No evidence was found suggesting that toxics were a likely stressor.

6.3. Possible Stressors

<u>Organic Matter</u>

Several factors were monitored that, if elevated, would indicate a problem due to increased levels of organic matter. These factors are total organic carbon (TOC), volatile suspended solids (VSS), dissolved oxygen (DO), biological oxygen demand (BOD), and chemical oxygen demand (COD). Graphs of each of these monitored factors are included in Figures 6.6 through 6.11. As can be seen from these graphs, all of these parameters were recorded at relatively low levels. The few TOC measurements available were all below the groundwater criteria of 10 mg/L. The monthly and diurnal DO measurements were all above the minimum daily average of 5.0 mg/L for Class IV waters. During the diurnal DO monitoring, temperatures ranged between 22.4 and 24.4 °C and the sky was overcast. The VSS and BOD_5 measurements were predominantly at their respective minimum detection limits of 3 mg/L, and 1 or 2 mg/L; measurements recorded at these levels could actually indicate much lower concentrations. In addition, the moderate scores of the shredders to filterers ratio (SC/CF) metric (Table 3.2) indicate limited amounts of organic matter (high levels of shredders indicate an abundance of their food supply – organic matter). The one factor that prevented this stressor from being eliminated altogether was that many samples at the old benthic station had elevated Multi-Family Biotic Index (MFBI) scores (Table 3.2) and contained large populations of Chironimidae and Simulidae, two species whose dominance tends to be indicative of moderate amounts of organic and nutrient enrichment.

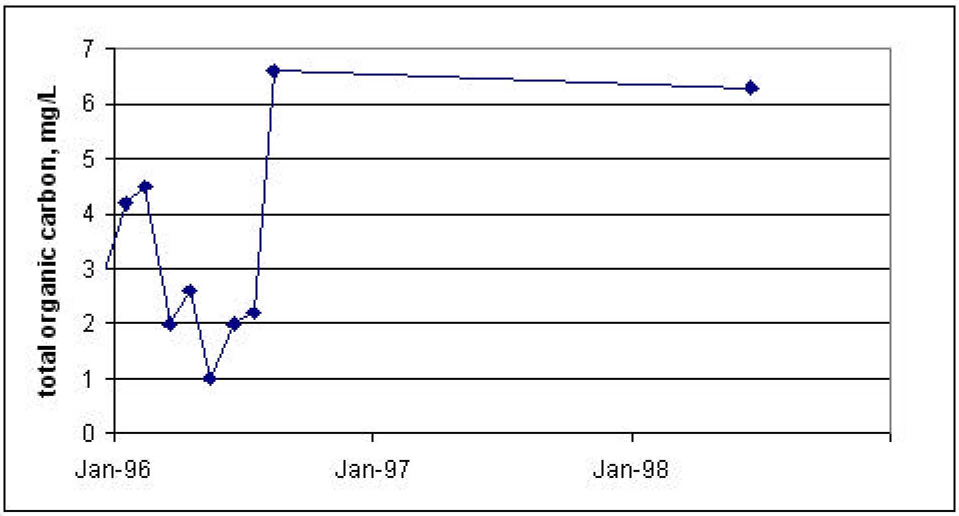


Figure 6.6. Total Organic Carbon Concentration in Linville Creek

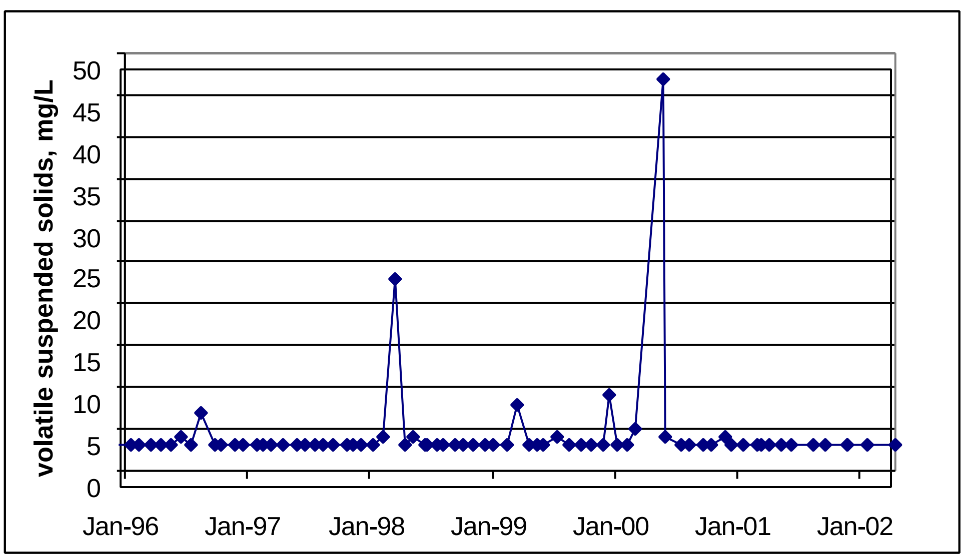


Figure 6.7. Volatile Suspended Solids Concentration in Linville Creek

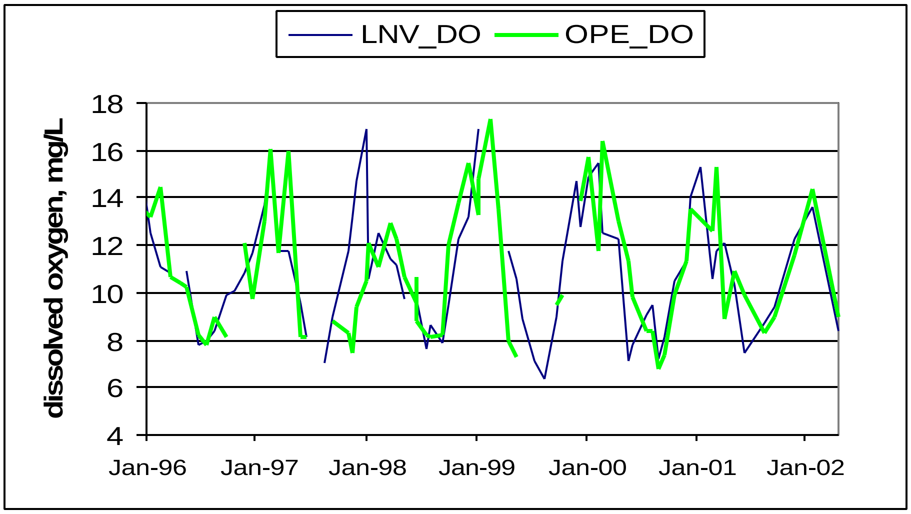


Figure 6.8. Monthly Dissolved Oxygen Concentration in Linville and Upper Opequon Creeks.

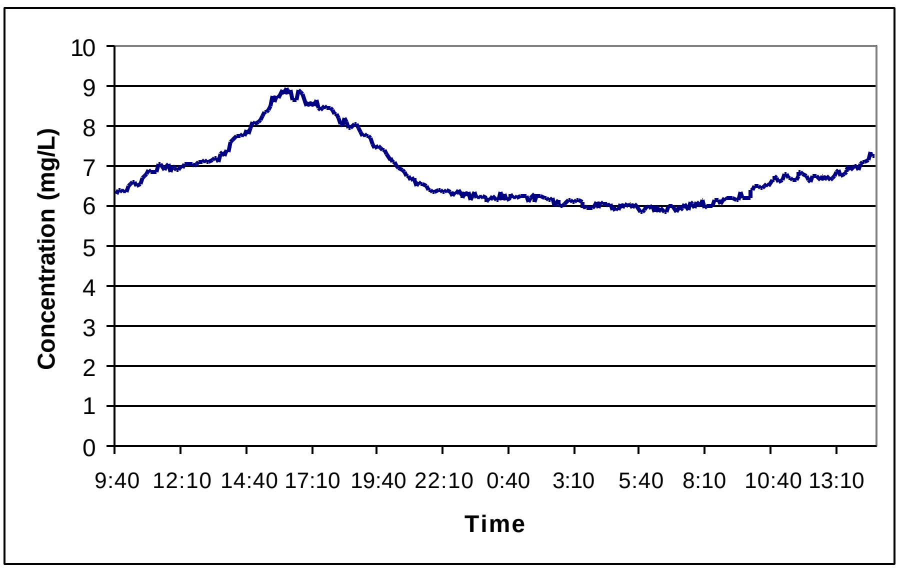


Figure 6.9. Diurnal Dissolved Oxygen Concentration in Linville Creek: July 24-25, 2002.

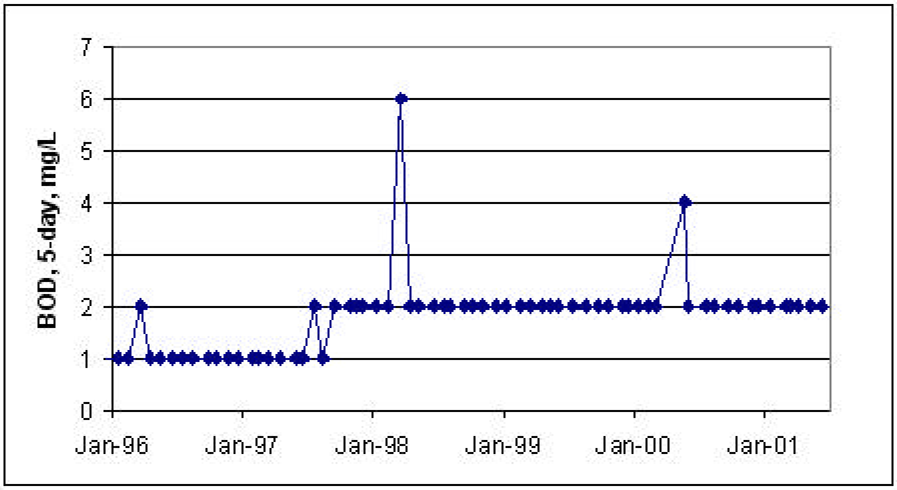


Figure 6.10. BOD (5-day) Concentration in Linville Creek

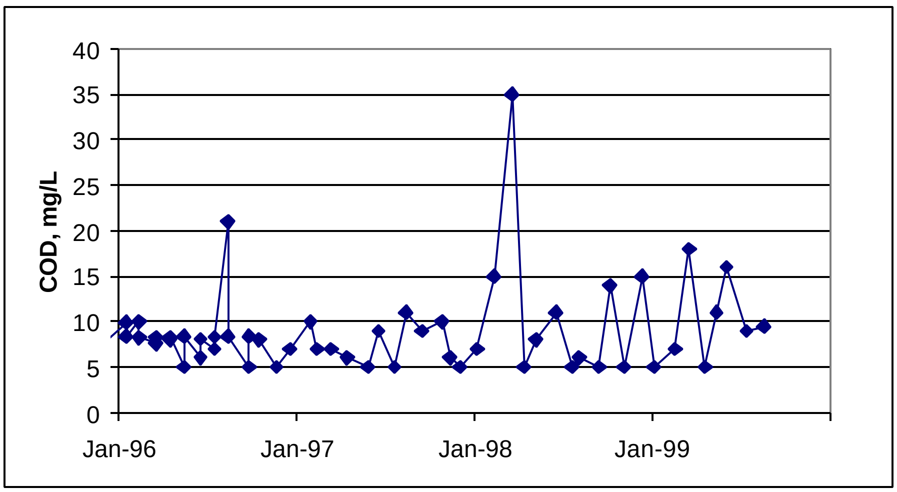


Figure 6.11. COD Concentration in Linville Creek

<u>Nutrients</u>

Nitrate (dissolved nitrogen) (Figure 6.12) and orthophosphate (dissolved phosphorus) (Figure 6.13) concentrations are above those needed for eutrophication (eutrophic sufficiency levels). Three samples had phosphorus concentrations above the DEQ “threatened waters” threshold of 0.2 mg/L. Linville Creek received a high total nitrogen (TOTN) rank in the VADCR 2000 Nonpoint Source Assessment. The ratio of nitrogen to phosphorus is 54.5, which indicates that phosphorus is the limiting nutrient. Even though nutrient levels are above eutrophic levels, because DO levels are not showing the impacts of accelerated algal growth, nutrients are not considered a likely stressor.

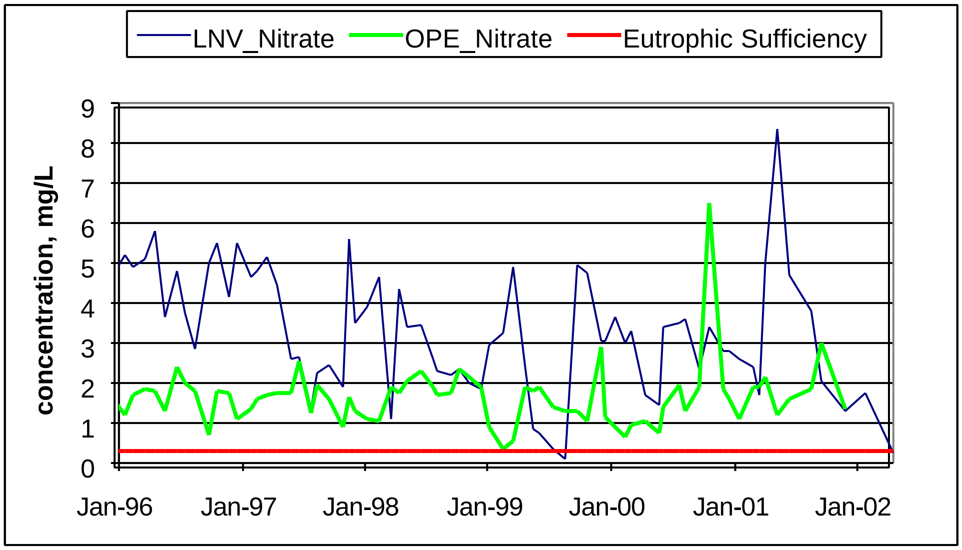


Figure 6.12. Nitrogen Concentrations in Linville and Upper Opequon Creeks.

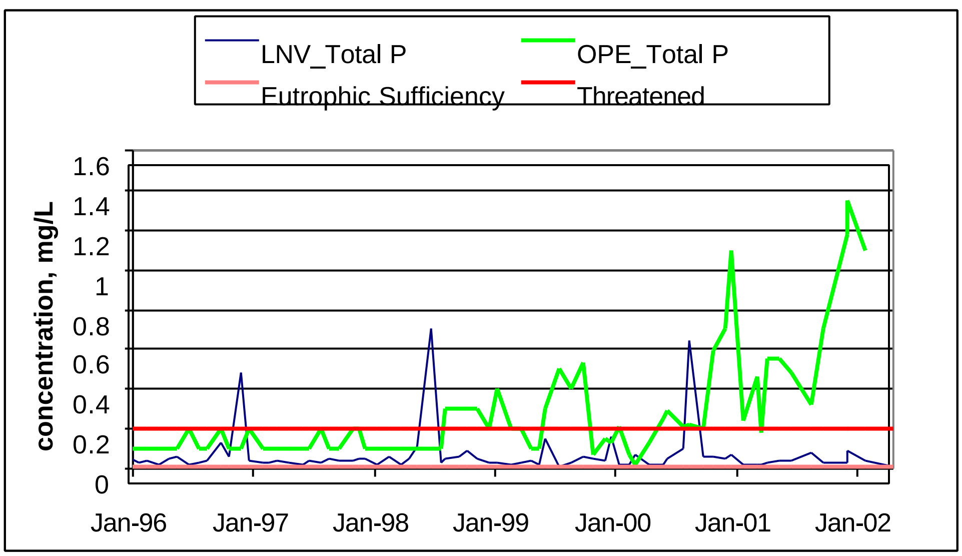


Figure 6.13. Phosphorus Concentrations in Linville and Upper Opequon Creeks.

6.4. Most Probable Stressor

Many of the %haptobenthos scores in the MAIS assessment (Table 3.3) were low, indicating poor habitat for functional groups requiring a coarse, clean sediment substrate. Linville Creek also received repeated low habitat scores for bank stability, substrate availability, bank vegetation, riparian vegetation, and embeddedness (Table 3.3). Additionally, there was observed trampling and damage to stream banks from livestock having access to the creek. Taken together, these observations support the case for sediment being the most likely stressor on the benthic community. Based on this analysis, sediment will be used as the target pollutant upon which the benthic TMDL for Linville Creek will be based. In addition, reductions in sediment loadings are usually associated with reductions in loadings from organic matter and nutrients. Thus, reductions in sediment loadings will also reduce possible impacts from these other potential stressors.

CHAPTER 7: THE REFERENCE WATERSHED MODELING APPROACH

7.1. Introduction

Because Virginia has no numeric in-stream criteria for sediment, a “reference watershed” approach was used to set allowable sediment loading rates in the impaired watershed.

The reference watershed approach pairs two watersheds – one whose streams are supportive of their designated uses and one whose streams are impaired. This reference watershed may or may not be the same as the biological reference watershed (i.e., the watershed used for determining comparative biological metric scores). The reference watershed is selected on the basis of similarity of land use, topographical, ecological, and soils characteristics with those of the impaired watershed. This approach is based on the assumption that reduction of the stressor loads in the impaired watershed to the level of the loads in the reference watershed will result in elimination of the benthic impairment.

The reference watershed approach involves assessment of the impaired reach and its watershed, identification of potential causes of impairment through a benthic stressor analysis, selection of an appropriate reference watershed, model parameterization of the reference and TMDL watersheds, definition of the TMDL endpoint using modeled output from the reference watershed, and development of alternative TMDL reduction (allocation) scenarios.

7.2. Selection of Reference Watershed for Sediment

7.2.1. Comparison

The initial list of potential reference watersheds was composed of all watersheds previously used as biological references for Linville Creek, the two watersheds most recently used as sediment reference watersheds for the Blacks Run and Cooks Creek watersheds, and one other watershed also used as a biological reference watershed in the same region. Because sediment was identified as the pollutant responsible for the benthic impairment, the comparison of watershed characteristics focused, not only on geologic and ecologic similarities, but also on sediment-generating characteristics. Minimal differences exist among the eco-region classifications for all of the potential reference watersheds. All watersheds are in the Central Appalachian Ridges and Valleys Level III ecoregion, and lie predominantly in the Northern Limestone/Dolomite Valleys Level IV ecoregion.

Table 7.1 compares the various physical and sediment-related characteristics of the candidate reference watersheds to the characteristics of the impaired watershed. The characteristics chosen to be representative of sediment generation and transport were land use distribution, non-forested average soil erodibility, and average non-forested percent slope. The Universal Soil Loss Equation (USLE) K-factor was used as an index of the erosivity of the soils in the watersheds, and was calculated as a weighted average of the soil K-factors in the watershed.

Table 7.1. Comparison of Physical and Sediment-Related Characteristics

			Landuse Distribution			Non-Forested K-factor		Non-Forested		Year 2000 Population			Spring 2002 RBP II	
Station ID	Stream Name	Area (ha)	Urban (%)	Forest (%)	Agr (%)	SSURGO	STATSGO	Slope (%)	Elevation (meters)	Non-Sewered	Total	Non-Sewered %	Score	% of Reference
LNV000.71	Linville Creek	12,046	2%	23%	75%	0.29	0.32	8.63	411.6	3,826	5,757	66%	20	47.6
OPE034.53	Opequon Creek	15,123	5%	35%	60%	0.31	0.30	5.60	224.1	16,322	19,809	82%	24	57.1
STC000.72	Strait Creek	672	0%	71%	29%	NA	0.24	18.50	988.3	57	57	100%	46	100
STY004.24	Stony Creek	19,768	1%	87%	12%	0.26	0.27	11.67	507.7	2,126	3,112	68%	10	23.8
BLP000.79	Bullpasture River	28,495	0%	81%	18%	NA	0.25	7.73	794.6	527	527	100%	44	95.6
CWP050.66	Cowpasture River	56,604	0%	86%	14%	NA	0.26	13.81	748.4	994	994	100%	42	100
HYS001.41	Hays Creek	20,801	0%	52%	48%	0.31	0.31	12.53	526.2	1,600	1,600	100%	36*	81.8
JKS067.00	Jackson River	31,429	0%	81%	19%	NA	0.26	13.93	848.7	705	705	100%	34*	77.3

* Hays Creek and Jackson River were last sampled in Fall 2000.

7.2.2. The Selected Reference Watershed

Based on the information presented in the previous two sections, the Upper Opequon Creek watershed was selected as the reference watershed for

Linville Creek. Land use distribution was considered the most important characteristic considered in this comparison, and the Upper Opequon was the only potential reference watershed with a significant urban component that was still predominantly comprised of agricultural land uses. The Upper Opequon watershed is located in the same Level III ecoregion as Linville Creek and shares the same major Level IV ecoregion. The Upper Opequon Creek watershed also is most similar in size to Linville Creek. The other characteristics - K-factors, slope, elevation, and percent non-sewered populations were very comparable to those of Linville Creek.

7.3. Sediment TMDL Modeling Endpoint

The reference watershed approach for Linville Creek uses the sediment loading rate in the non-impaired Upper Opequon watershed as the TMDL target endpoint. Reductions from various sources will be specified in the alternative TMDL scenarios that achieve the TMDL target within the impaired Linville Creek watershed. Reductions in sediment load to levels found in the reference watershed are expected to allow benthic conditions to return to a non-impaired state.

CHAPTER 8: MODELING PROCESS FOR SEDIMENT TMDL DEVELOPMENT

8.1. Introduction

8.2. Source Assessment of Sediment

Sediment is generated in the Linville Creek watershed through the processes of surface runoff; channel erosion, which includes streambank erosion and trampling by livestock; and from point source inputs. Sediment generation is accelerated through human-induced land-disturbing activities related to a variety of agricultural, forestry, and urban land uses.

8.2.1. Surface Runoff

During runoff events, sediment loading occurs from both pervious and impervious surfaces in the watershed. For pervious areas, soil is detached by rainfall impact and transported by overland flow to nearby streams. Vegetative cover, soil erodibility, slope, slope length, rainfall intensity and duration, and land management practices influence this process. During periods without rainfall, dirt, dust, and fine sediment build up on impervious areas through dry deposition, which is then subject to washoff during rainfall events. Sediment generated from impervious areas can also be influenced through management practices, such as street sweeping, which can reduce the surface load subject to washoff.

8.2.2. Channel Erosion

Channel erosion is a natural geologic process that occurs within the stream channel during runoff events, contributing to watershed sediment loads. Channel erosion is also increased by upstream human-induced land-disturbing activities that increase the frequency and magnitude of runoff events. Animals on pastures with access to streams also contribute to channel erosion. Livestock hooves detach clumps of soil from stream banks, and push the loosened soil downslope into streams adjacent to these areas, delivering sediment to the stream independent of runoff events.

8.2.3. Point Source TSS Loads

Fine sediment is included in total suspended solids (TSS) loads that are permitted for various VPDES and 1000 gpd facilities within the watershed (see Section 8.5.3).

8.3. GWLF Model Description

The Generalized Watershed Loading Functions (GWLF) model was developed for use in ungaged watersheds (Haith *et al*., 1992). The Visual Basic version of GWLF with modifications for use with ArcView (AVGWLF) was used in this study (Evans *et al*., 2001). Additional modifications were made to the model to allow for variable inputs and outputs of sediment buildup and washoff from impervious surfaces.

Loading functions are used as a compromise between the empiricism of export coefficients and the complexity of comprehensive water quality simulation models. GWLF is a continuous simulation spatially-lumped parameter model that operates on a daily time step. The model estimates runoff, sediment, and dissolved and attached nitrogen and phosphorus loads to streams from watersheds with a combination of point and non-point sources of pollution. The model considers flow inputs from both surface runoff and groundwater, and nutrient inputs from septic systems. The hydrology in the model is simulated with a daily water balance procedure that takes into consideration various types of storages within the system. Runoff is generated based on the Soil Conservation Service’s Curve Number method as presented in Technical Release 55 (SCS, 1986). Erosion is generated using a modification of the Universal Soil Loss Equation. The sediment supply component uses a delivery ratio together with the erosion estimates, and sediment transport is estimated by considering the transport capacity of the runoff. Channel erosion is modeled using the relationships developed by Evans in AVGWLF (Personal Communication, B. M. Evans, 2002).

The GWLF model requires three input files for weather, transport, and nutrient data. The weather file contains daily temperature and precipitation for the period of simulation. The transport file contains primarily input data related to hydrology and sediment transport, while the nutrient file contains nutrient values for the various land uses, point sources, and septic systems.

The following modifications were made to the Penn State Visual Basic version of the GWLF model, as incorporated in their ArcView interface for the model, AVGWLF v. 3.2:

- Although the model simulations are hard coded to begin in April the model was recoded to output data beginning with the following January for obtaining summary results on a calendar year basis.
- Urban sediment washoff was added to replace an erroneous formula that calculated USLE erosion from impervious areas.
- The groundwater flow component was modified in order to match minimum base flows estimated by the Chesapeake Bay Watershed Model for a statewide nonpoint source assessment study conducted for Virginia watersheds (Yagow, 2002).
- A regional ET adjustment factor was added.
- The conditional assignment of dissolved N and P concentrations to each agricultural land use receiving manure was corrected.
- A procedure was developed to automatically calculate a correction factor to account for differences between calculations of watershed total sediment yield and summations of sediment yield from individual land uses. Since the correction applied only to the organic component, nutrients were separated into dissolved and organic components.

8.4. Input Data Requirements

8.4.1. Climatic Data

Hourly precipitation and temperature data were obtained from the National Weather Service stations closest to each watershed, as shown in Table 8.1 and Figure 8.1. Missing data and distributions in the weather file were filled in based on the available weather records from surrounding stations. The hourly precipitation data were summed as daily totals, the hourly temperature data were transformed to daily averages, and both were converted to their respective metric units (cm and °C) for use with the GWLF model. From earlier work with the statewide NPS assessment as part of Virginia's 2002 305(b) report (Yagow, 2002), a statewide Thiessen polygon layer had been created from 153 available NWS daily weather stations in Virginia. The daily sequence of precipitation and temperature values for the GWLF model was calculated as a Thiessen weighted average of the two closest stations using the weights listed in Table 8.1. Weather data for the Timberville station (4.5 miles NE of the watershed) were not available after 1995, so during the 1996-1999 period, precipitation and temperature data for Linville were obtained solely from the Dale Enterprise station (approximately 1.5 miles southwest of the watershed).

Table 8.1. Weather Data Sources.

Watershed	Weather Station	NWS Coop ID	Thiessen Weight
Linville Creek	Dale Enterprise	442208	0.7370
	Timberville	448448	0.2630
Upper Opequon Creek	Winchester WINC	449181	0.6604
	Winchester 7 SE	449186	0.3396

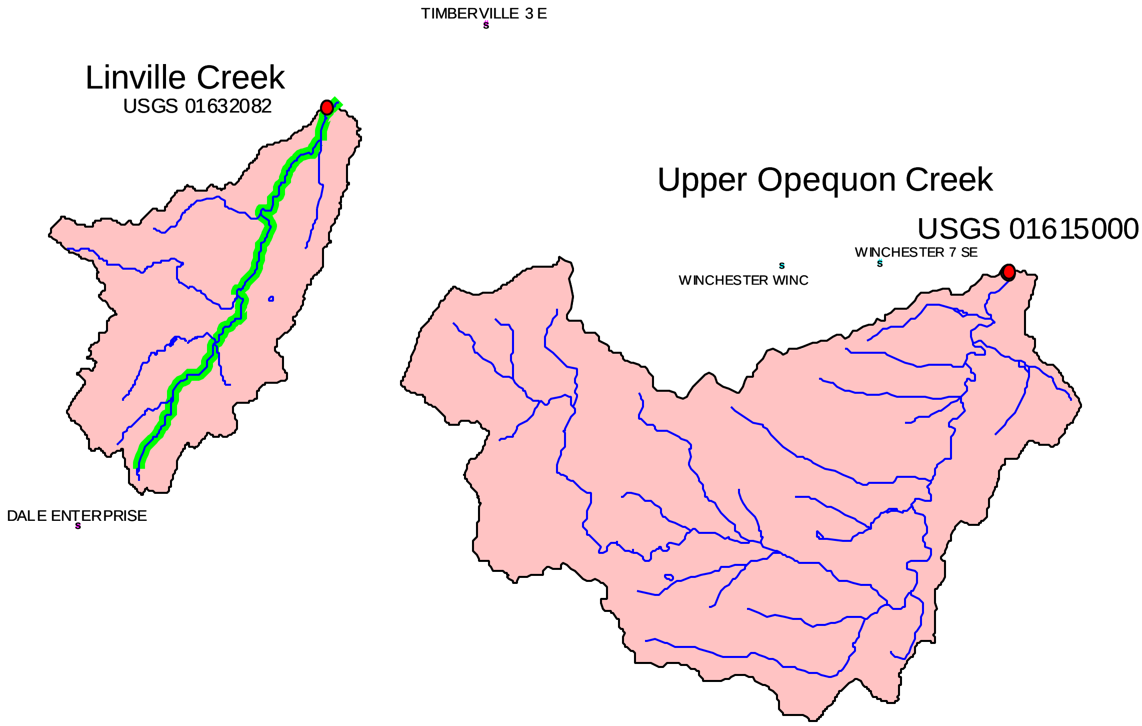


Figure 8.1. Location of USGS Flow Gages and NWS Weather Stations for Linville and Upper Opequon Watersheds.

8.4.2. Land Use

Linville Creek has a detailed digital land use layer, developed by the VADCR from digital ortho-photo quarter quads, to assist HSPF model development for the Linville Creek bacteria TMDL. However, a comparable digital land use data layer was not available for the Upper Opequon. Therefore, a decision was made to use the Multi-Resolution Land Characteristics (MRLC) 2000 digital land use layer as the land use source for both watersheds, to maintain consistency between the two watersheds. As part of the 2002 Statewide Nonpoint Source Pollution Assessment for the Virginia 305(b) Report, VADCR modified the MRLC land use categorization and included several derived land use categories to facilitate accounting for best management practice (BMP) implementation, as shown in Table 8.2. The nine land use categories and their distribution within the Linville Creek and the Upper Opequon Creek watersheds are shown in Table 8.3.

Table 8.2. Consolidation of MRLC Land Use Categories

MRLC Class	MRLC Code	Original MRLC Categories	Categories Used for GIS Parameter Derivation	Categories for Bay Model Comparison/Calibration	Categories for DCR Load Assessment
1	11	open water			
8 9 10 11 12	42 43 41 91 92	evergreen forest mixed forest deciduous forest woody wetlands emergent herbaceous wetlands	forest (S)	forest	forest disturbed forest[2] (5 * DOF clear cut area)
5	81	pasture/hay (S)		pasture hay manure acres[1]	pasture hay manure acres[1]
6	82	row crops (S)		high till cropland low till cropland	high till cropland low till cropland
7	85	urban/recreational grasses (S)	herbaceous urban (HERB)	pervious urban = 0.9*HERB + 0.6*LO + 0.15*HI + 0.6*EXP	pervious urban = 0.9*HERB + 0.6*LO + 0.15*HI + 0.6*EXP + (MRLC 15 - DOF clearcut area)
2	21	low intensity residential (S)	low intensity urban (LO)		
3 4	22 23	high intensity residential commercial/industrial/transportation	high intensity urban (HI) (S)	impervious urban = 0.1*HERB + 0.4*LO + 0.85*HI + 0.4*EXP	impervious urban = 0.1*HERB + 0.4*LO + 0.85*HI + 0.4*EXP
13 14	32 31	quarries/strip mines/gravel pits bare rock/sand/clay	exposed (EXP) (S)		
15	33	transitional (S)		mixed open	disturbed forest[2] (DOF clearcut area)

[1] Manure acres is a derived land use category based on U. S. Agriculture Census livestock populations.
[2] Disturbed forest = Dept. of Forestry (DOF) clear cut area * 5, the annual clearcut area plus 4 years of regrowth.

Table 8.3. Land Use Distributions

Land Use Categories	Linville (ha)	Linville (%)	Upper Opequon (ha)	Upper Opequon (%)
High Till	459.5	3.8%	588.7	3.9%
Low Till	462.6	3.9%	451.1	3.0%
Hay	2,779.4	23.1%	2,873.2	19.1%
Pasture	4,804.9	40.0%	3,986.0	26.5%
Manure Acres	0.9	0.0%	0.1	0.0%
Forest	3,052.6	25.4%	5,499.3	36.6%
Disturbed Forest	12.2	0.1%	433.4	2.9%
Pervious Urban	288.1	2.4%	759.5	5.0%
Impervious Urban	155.1	1.3%	453.2	3.0%
Total Watershed Area (ha)	12,015.2		15,044.5	

8.4.3. Hydrologic Parameters

The Upper Opequon watershed was recently used as a reference watershed for the Blacks Run TMDL (Tetra Tech, 2002) and was modeled using the GWLF model. Ideally, this set of calibrated parameters could be used in an identical fashion with the Linville TMDL. However, as development of the databases proceeded for the Linville and Upper Opequon watersheds, a different categorization of land uses was selected to better represent the potential pollutants. The new categorization process necessitated a re-evaluation and re-calibration of parameter values for the Upper Opequon. The re-evaluation was also consistent with our principle of evaluating all parameters using the same procedures for each watershed, in order to maintain their comparability for the reference watershed approach. The GWLF parameter values were evaluated from a combination of GWLF user manual guidance, AVGWLF procedures, procedures developed during the statewide NPS pollution assessment, best professional judgment, and values used in the Blacks Run TMDL (Tetra Tech, 2002). Parameters were generally evaluated using GWLF manual guidance, except where noted otherwise. Hydrologic and sediment parameters are all included in GWLF's transport input file with the exception of urban sediment buildup rates, which are in the nutrient input file.

Watershed-Related Parameter Descriptions

- Unsaturated Soil Moisture Capacity (SMC): The amount of moisture in the root zone, evaluated as a function of the area-weighted soil type attribute - available water capacity.
- Recession coefficient (day^{-1}): The recession coefficient is a measure of the rate at which streamflow recedes following the cessation of a storm, and is approximated by averaging the ratios of streamflow on any given day to that on the following day during a wide range of weather conditions, all during the recession limb of each storm's hydrograph.
- Seepage coefficient (day-1): The seepage coefficient represents the amount of flow lost as seepage to deep storage.

The following parameters were initialized by running the model for a 9-month period prior to the selected period for which loads were calculated:

- Initial unsaturated storage (cm): Initial depth of water stored in the unsaturated (surface) zone.
- Initial saturated storage (cm): Initial depth of water stored in the saturated zone.
- Initial snow (cm): Initial amount of snow on the ground at the beginning of the simulation.
- Antecedent Rainfall for each of 5 previous days (cm): The amount of rainfall on each of the five days preceding the first day in the weather file.

Month-Related Parameter Descriptions

- Month: Months were ordered, starting with April and ending with March, in keeping with the design of the GWLF model and its assumption that stored sediment is flushed from the system at the end of each April-March cycle. Model output was modified in order to summarize sediment loads on a calendar-year basis.
- ET_CV: Composite evapo-transpiration cover coefficient, calculated as an area-weighted average from land uses within each watershed.
- Hours per Day: Mean number of daylight hours.
- Erosion Coefficient: This is a regional coefficient used in Richardson's equation for calculating daily rainfall erosivity. Each region is assigned separate coefficients for the months of October-March, and for April-September. Values used were from the Blacks Run TMDL (Tetra Tech, 2002).

Land Use-Related Parameter Descriptions

- Curve Number: The SCS curve number (CN) is used in calculating runoff associated with a daily rainfall event.

8.4.4. Sediment Parameters

Watershed-Related Parameter Descriptions

- Sediment delivery ratio: The fraction of erosion – detached sediment – that is transported or delivered to the edge of the stream, calculated as an inverse function of watershed size (Evans *et al*., 2001).

Land Use-Related Parameter Descriptions

- USLE K-factor: The soil erodibility factor was calculated as an area-weighted average of all component soil types.
- USLE LS-factor: This factor is calculated from slope and slope length measurements by land use. Slope is evaluated by GIS analysis, and slope length is calculated as an inverse function of slope.
- USLE C-factor: The vegetative cover factor for each land use was evaluated following GWLF manual guidance, Wischmeier and Smith (1978), and Hession *et al*. (1997).
- Daily sediment buildup rate on impervious surfaces: The daily amount of dry deposition deposited from the air on impervious surfaces on days without rainfall, assigned using GWLF manual guidance.

Channel Erosion Parameter Descriptions

- % Developed land: percentage of the watershed with urban-related land uses.
- Animal density: calculated as the number of beef and dairy 1000-lb equivalent animal units (AU) divided by the watershed area in acres.
- Soil erodibility: Watershed-averaged soil erodibility (USLE K-factor).
- Number: Watershed-averaged runoff curve number (CN).
- Total stream length in meters.
- Stream length with livestock access: calculated as the total stream length in the watershed where livestock have unrestricted access to streams, resulting in streambank trampling, in meters.

8.5. Sediment Pollutant Sources

8.5.1. Surface Runoff

Pervious area sediment loads were modeled explicitly in the GWLF using sediment detachment, a modified USLE erosion algorithm, and a sediment delivery ratio to calculate edge-of-stream (EOS) loads and are reported on a monthly basis by land use. Impervious area sediment loads were modeled explicitly in GWLF using an exponential buildup-washoff algorithm.

8.5.2. Channel Erosion

Channel erosion was modeled explicitly within GWLF using the algorithms included in the AVGWLF adaptation of the GWLF model (Evans *et al*., 2001). In these equations, channel erosion is calculated as a function of daily stream flow volume and a coefficient developed through regression. The regression coefficient is calculated as a function of the percentage of developed land, animal density, watershed-averaged soil erodibility, the watershed-averaged runoff curve number, and the total stream length. For the TMDL allocation scenarios, the reduction from restricting livestock access to streams was calculated as the product of the percentage of total stream length with livestock access, the percentage reduction of livestock access corresponding with the fecal coliform TMDL, and an estimated percentage of the channel erosion due to trampling, where livestock had stream access.

8.5.3. Point Sources

Because the reference watershed TMDL is calculated based on relative existing unit area loads, estimates of actual contributions were performed for existing conditions, rather than permitted conditions. Sediment loads from point sources were calculated using TSS concentrations and flow volumes. For a detailed list of general permitted point source dischargers, see Table 4.3. For permitted VPDES facilities (Table 4.2), available monthly daily monitoring report (DMR) data for each facility (maximum Concentration and maximum Daily Flow) were used to calculate TSS daily loads for each monthly sample. The average of all of these samples was calculated and multiplied by 365¼ days/yr to represent the average annual existing sediment load from each facility in the Linville and Upper Opequon watersheds, as reported in Table 8.4. For the TMDL calculations, permitted point source discharge contributions were calculated as the maximum permitted daily flow multiplied by the maximum permitted TSS concentration.

Table 8.4. Average Annual Existing Point Source TSS Loads (t/yr).

Linville Creek Point Sources			Upper Opequon Creek Point Sources		
VPDES ID	**Name**	**TSS (Mg/yr)**	**VPDES ID**	**Name**	**TSS (Mg/yr)**
85588	Field Unit #8	0.091	27600	A & K Car Wash	0.006
79898	Broadway STP	0.098	75191	Parkins Mill STP	8.084
			88471	Frederick Co. Landfill	2.711
			88722	Stonebrook STP	0.011
			89010	Franciscan Center	0.001
VPDES Facility Totals		0.19			10.81
1000 gpd Units	28 units	1.16		15 units	0.62
Point Source Totals		**1.35**			**11.43**

Because the 1000 gpd facilities are covered under a general permit, no monthly DMR data were required or available. Therefore, sediment loads for these facilities were calculated as the number of facilities multiplied by the annual permitted TSS load for each facility. The permitted daily average TSS concentration of 30 mg/L translates into an annual TSS load of 0.0415 t/yr for each unit, with the totals also given in Table 8.4.

Sediment loads from both VPDES and 1000 gpd facilities were calculated in spreadsheets outside of the GWLF model and added to GWLF model outputs prior to analysis.

8.6. Critical Conditions and Seasonal Variations

8.6.1. Critical Conditions

The GWLF model is a continuous simulation model that uses daily time steps for weather data and water balance calculations. The period of rainfall selected for modeling was chosen as a multi-year period that was representative of typical weather conditions for the area, and included “dry,” “normal,” and “wet” years. The model, therefore, incorporated the variable inputs needed to represent critical conditions during low flow, generally associated with point source loads, and critical conditions during high flow, generally associated with nonpoint source loads.

8.6.2. Seasonal Variability

The GWLF model used for this analysis considered seasonal variation through a number of mechanisms. Daily time steps were used for weather data and water balance calculations. The model also used monthly-variable parameter inputs for evapo-transpiration cover coefficients, daylight hours/day, and rainfall erosivity coefficients for user-specified growing season months.

8.7. Model Calibration for Hydrology

The GWLF model was originally developed for use in ungaged watersheds (Haith *et al*., 1992). However, the BasinSim adaptation of the model (Dai *et al*., 2000) recommends hydrologic calibration of the model, and preliminary calibrated model results for the gaged Linville Creek watershed showed an 18% reduction in the percent error between simulated and observed monthly runoff. Because observed runoff data were available at both Linville Creek and its reference watershed, Upper Opequon Creek, it was logical to perform hydrologic calibration on both watersheds. Because GWLF was used to compare the simulation results between the target and its reference watershed, both watersheds were calibrated in a similar manner.

The purpose of calibration was to adjust parameter values within the model so that simulated model output more closely matched observed data. The reason for performing the hydrologic calibration was to enable simulation of the hydrology-dependent components as accurately as possible. The purpose of calibration for the reference watershed approach was to provide a more representative total flow and flow distribution on which to base the sediment loading functions. The TMDL modeling runs for future conditions were made using the same weather files that were used for calibration.

The National Weather Service (NWS) has a much denser network of stations for recording rainfall than does the U.S. Geological Survey (USGS) for recording daily flow. Therefore, in any calibration effort, flow data are generally the limiting factor. Fortunately, USGS flow gages are located near the outlets of both the Linville and the Upper Opequon Creek watersheds. Daily observed flow measurements were obtained for both stations and compared with GWLF model output. Figure 8.1 shows the location of both the USGS flow gages and NWS precipitation gages in relation to each watershed, and Table 8.5 shows the available period of record for each station.

Table 8.5. Available USGS Daily Flow Data

Watershed	USGS Gage#	Daily Flow Record
Linville Creek	01632082	08-09-1985 to 09-30-2001
Upper Opequon Creek	01615000	10-01-1943 to 10-17-1997

The common period of record between these two stations is 08-09-1985 to 10-17-1997, which contains approximately 12 years of data. The calibration period was chosen as the most recent 10-year period on a calendar year basis, 1988–1997. This resulted in a calibration period for the Upper Opequon watershed that was three months shorter than the period for the Linville Creek watershed.

GWLF uses daily rainfall inputs and generates monthly runoff outputs. Hydrologic calibration was performed based on monthly runoff (flow) totals. The parameters adjusted during hydrologic calibration included land use curve numbers, the recession coefficient, and the seepage coefficient. GWLF can produce outputs of monthly surface runoff by land use, as well as monthly groundwater flow, which is assumed to represent the base flow component. Calibration was performed separately on base flow and surface runoff. The USGS software program HYSEP (Sloto and Crouse, 1996) was used to estimate the percentage of base flow for each watershed, as summarized in Table 8.6, using the local minimum option of that program.

Table 8.6. Results from HYSEP Baseflow Separation

Watershed	USGS #	Period Assessed	Monthly Baseflow %		
			Min	**Mean**	**Max**
Linville Creek	01632082	01/88 – 12/97	44.2	61.4	75.0
Upper Opequon Creek	01615000	01/88 – 09/97	36.6	48.4	66.4

Spreadsheets were constructed and used to analyze model output after each model run, and to calculate parameter adjustments for the next iteration of calibration. Within the spreadsheets, comparisons were made between simulated and observed runoff for the flow components, seasonal distribution, monthly runoff time series, and cumulative runoff. Base flow was calibrated through adjustments to the recession and seepage coefficients, while surface runoff was calibrated by adjusting the land use-related SCS curve numbers.

The results of the hydrologic calibration for Linville Creek are presented as the monthly runoff time series in Figure 8.2 and cumulative runoff in Figure 8.3, along with the flow and seasonal distributions in Table 8.7. Corresponding results for Upper Opequon Creek are presented in Figures 8.4 and 8.5 and Table 8.8.

The monthly runoff time series for Linville showed a generally good correspondence between observed and simulated monthly runoff, with a correlation coefficient of 0.917. Total simulated runoff was 0.2% less than the observed value. The simulated percentages of runoff distributed among seasons were all within 10% of observed values, with the exception of summer runoff. The difference between observed and simulated individual season average annual runoff totals were within ±0.6 cm/yr.

The monthly runoff time series for Upper Opequon also showed a generally good correspondence between observed and simulated monthly runoff, with a correlation coefficient of 0.939. Total simulated runoff was only 2.9% less than the observed value. The simulated percentages of runoff distributed among seasons were all within 10% of observed values with the exception of fall runoff.

The difference between observed and simulated individual season average annual runoff totals were within ±1.0 cm/yr.

Table 8.9 summarizes the changes made during calibration for the three GWLF parameters used for hydrologic calibration. In order to approximate the percentage of total inflow coming from surface runoff during calibration, it was necessary to increase the curve numbers to unusually high values. Therefore, rather than adjusting base flow to the HYSEP average base flow value, a higher value was chosen within the observed range for each station. The base flow percentage was increased to the mean + 2/3 x (maximum – mean) in order to reduce the curve numbers to more reasonable values. Even with the base flow adjustment, however, it was still necessary to increase most of the land use-related runoff curve numbers by 15-16% above those recommended by NRCS and GWLF guidance documents in order to match observed runoff.

In summary, the correlations between simulated and observed total runoff in both watersheds were quite good with correlation coefficients above 90%. Cumulative monthly runoff over the 10-year period was matched within 2.7% of observed totals. The division of flow between surface runoff and base flow was within 3% of the adjusted HYSEP base flow percentage for each watershed. A slightly larger variability was seen in the distribution among seasons, although even these were mostly within 10%. Part of these differences can be explained by the expected variability between measurements at a single precipitation station and how rainfall is actually distributed over an entire watershed. The major part of the differences, however, relate to the fact that the GWLF model is a daily time-step, lumped parameter model. As such, it would be very surprising indeed, if it replicated all flow regimes and seasonal distributions consistently under all conditions. However, because the reference watershed approach uses average loading over long periods and utilizes comparably parameterized and calibrated watersheds, the calibrated GWLF model should provide reasonable load comparisons for development of a TMDL.

A complete listing of all GWLF parameter values evaluated for the GWLF transport file for both watersheds during hydrologic calibration are shown in Tables 8.10 through 8.12. Table 8.10 lists the various watershed-wide parameters and their values, Table 8.11 displays the monthly variable evapo-transpiration cover coefficients, and Table 8.12 details the various land use-related parameters.

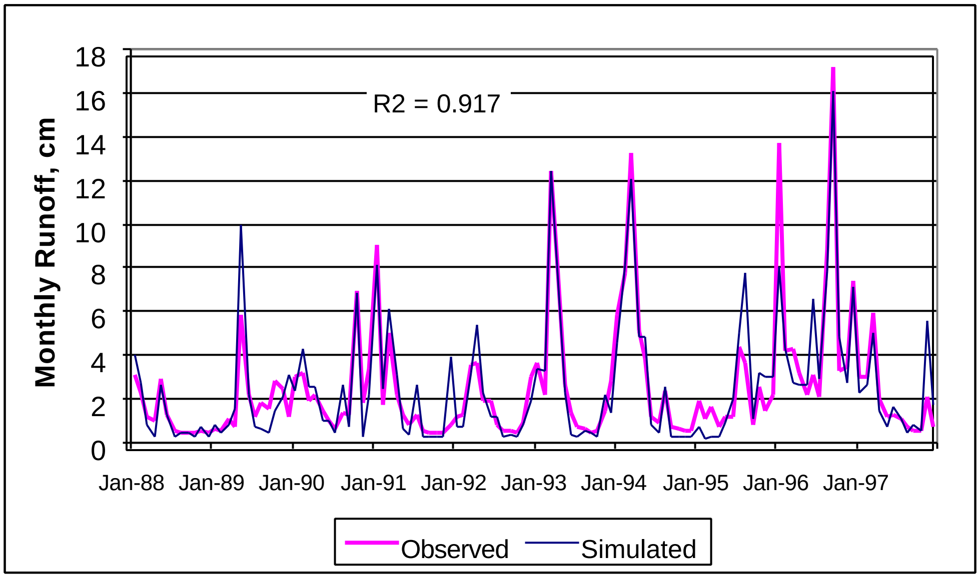


Figure 8.2. Calibration Monthly Runoff Time Series – Linville Creek

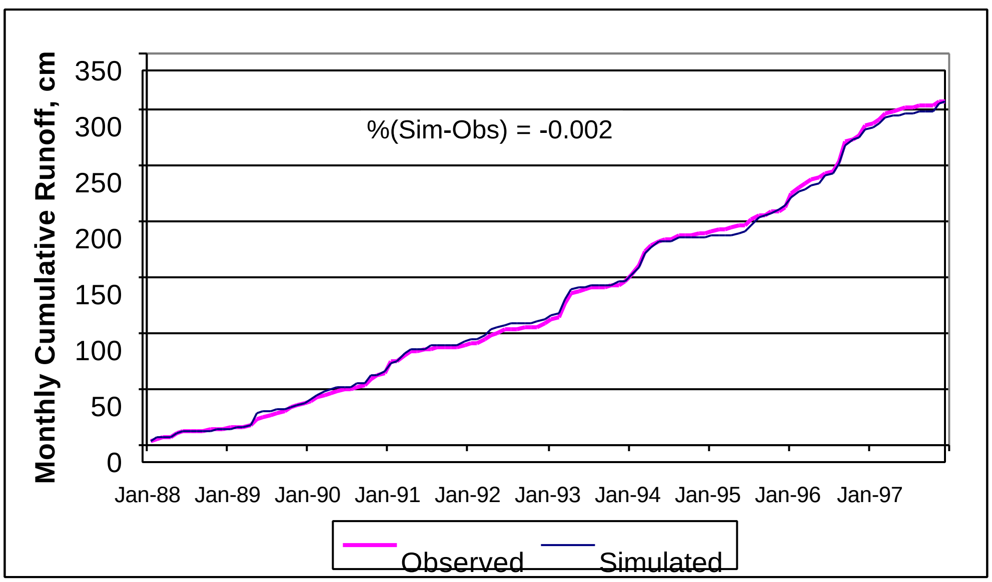


Figure 8.3. Calibration Cumulative Runoff – Linville Creek

Table 8.7. Calibration Flow Distributions – Linville Creek – 1988-1997

Flow Distribution Components	SIMULATED (cm/yr)	SIMULATED (% of Total)	OBSERVED (cm/yr)	OBSERVED (% of Total)	Sim-Obs (% of Total)	Target Baseflow
Total Runoff	30.64		30.71			
Total Surface Runoff	8.62	28.2%	12.15	39.6%		
Total Baseflow	22.01	71.8%	18.56	60.4%	2.3%	69.6%
Winter (Dec-Feb) Runoff	8.92	29.1%	9.51	31.0%	-6.2%	
Spring (Mar-May) Runoff	10.42	34.0%	10.40	33.9%	0.2%	
Summer (Jun-Aug) Runoff	5.58	18.2%	5.00	16.3%	11.7%	
Fall (Sep-Nov) Runoff	5.71	18.6%	5.80	18.9%	-1.5%	

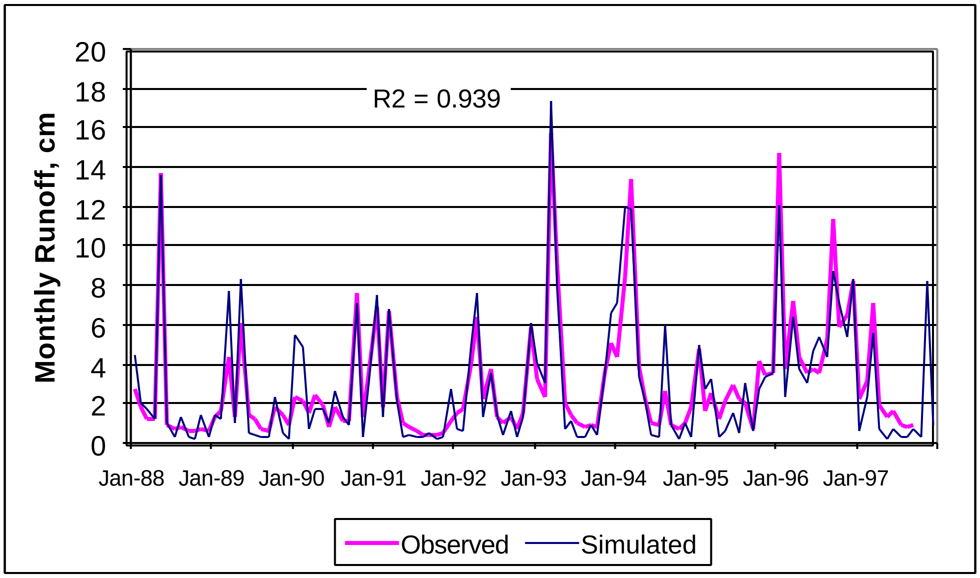


Figure 8.4. Calibration Monthly Runoff Time Series – Upper Opequon Creek

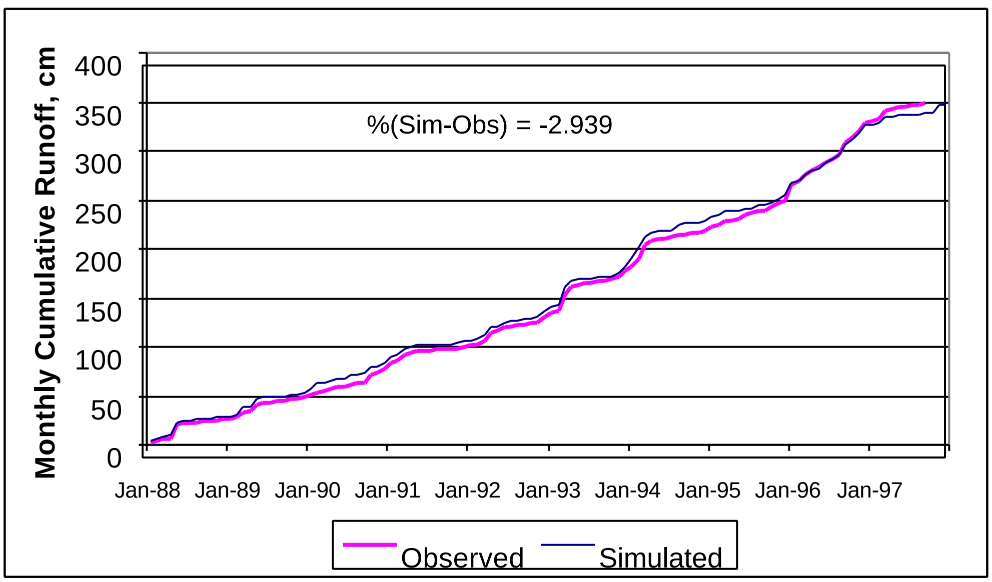


Figure 8.5. Calibration Cumulative Runoff – Upper Opequon Creek

Table 8.8. Calibration Flow Distributions – Upper Opequon Creek

Flow Distribution Components	SIMULATED (cm/yr)	SIMULATED (% of Total)	OBSERVED (cm/yr)	OBSERVED (% of Total)	Sim-Obs (% of Total)	Target Baseflow
Total Runoff	34.57		35.64			
Total Surface Runoff	15.41	44.6%	19.06	53.5%		
Total Baseflow	19.16	55.4%	16.58	46.5%	-3.1%	58.5%
Winter (Dec-Feb) Runoff	11.60	33.5%	10.69	30.0%	8.4%	
Spring (Mar-May) Runoff	12.80	37.0%	13.43	37.7%	-4.7%	
Summer (Jun-Aug) Runoff	4.44	12.8%	4.87	13.7%	-8.8%	
Fall (Sep-Nov) Runoff	5.73	16.6%	6.65	18.7%	-13.8%	

Table 8.9. GWLF Hydrology Calibration Parameters

	Linville		Upper Opequon	
Parameter	**Evaluated**	**ReCalib**	**Evaluated**	**ReCalib**
recession coefficient	0.0806	0.0600	0.1112	0.1500
seepage coefficient	0.0376	0.0000	0.0466	0.0000
Landuse Category	**Landuse-Based CNs**			
hi-till cropland	83.60	96.98	85.01	99.04
lo-till cropland	81.73	94.81	83.09	96.84
hay	74.55	86.48	76.44	89.44
pasture	75.15	87.17	77.15	90.30
manure acres	98.00	98.00	98.00	98.00
forest	67.98	78.86	70.49	83.20
disturbed forest	89.09	99.00	90.18	99.60
pervious urban	75.15	87.17	77.15	90.30
impervious urban	99.50	99.80	99.50	99.70

Table 8.10. GWLF Watershed Parameters

GWLF Watershed Parameters	Units	Linville	Upper Opequon
recession coefficient	(day^{-1})	0.06	0.15
seepage coefficient	(day^{-1})	0.00	0
sediment delivery ratio		0.1084	0.1014
unsaturated water capacity	(cm)	15.30	14.04
erosivity coefficient (Nov - Apr)		0.1	0.1
erosivity coefficient (Growing Season)		0.3	0.3
% developed land	(%)	5.97	5.79
no. of livestock	(AU)	9,106	1,253
area-weighted soil erodibility		0.284	0.292
area-weighted runoff curve number		75.9	77.4
total stream length	(m)	58,902	114,489
stream length with livestock access	(m)	28,968	33,394

Table 8.11. Monthly Evapo-Transpiration Cover Coefficients

Watershed	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Linville	0.962	0.973	0.977	0.977	0.977	0.964	0.913	0.824	0.748	0.722	0.849	0.936
Upper Opequon	0.926	0.94	0.945	0.945	0.945	0.929	0.867	0.758	0.664	0.633	0.789	0.895

Table 8.12. Land Use-Related GWLF Erosion Parameters.

Landuse Category	Linville			Upper Opequon		
	Area (ha)	Curve Number	KLSCP	Area (ha)	Curve Number	KLSCP
hi-till cropland	459.5	96.98	1.054	588.7	99.04	0.653
lo-till cropland	462.6	94.81	0.464	451.2	96.84	0.287
hay	2779.4	86.48	0.042	2873.2	89.44	0.025
pasture	4804.9	87.17	0.042	3986.0	90.30	0.025
manure acres	0.9	98.00	0.000	0.1	98.00	0.000
forest	3052.6	78.86	0.002	5499.3	83.20	0.001
disturbed forest	12.2	99.00	0.590	433.4	99.60	0.420
pervious urban	288.1	87.17	0.007	759.5	90.30	0.008
impervious urban	155.1	99.80	0.000	453.2	99.70	0.000

CHAPTER 9: TMDL ALLOCATIONS

The objective of a TMDL is to allocate allowable loads among different pollutant sources so that the appropriate control actions can be taken to achieve water quality standards (USEPA, 1991).

9.1. Bacteria TMDL

9.1.1. Background

The objective of the bacteria TMDL for Linville Creek was to determine what reductions in *E. coli* loadings from point and nonpoint sources are required to meet state water quality standards. The state water quality standards for *E. coli* used in the development of the TMDL were 126 cfu/100mL (calendar-month geometric mean) and 235 cfu/100mL (single sample maximum). The TMDL considers all sources contributing *E. coli* to Linville Creek. The sources can be separated into nonpoint and point (or direct) sources. The incorporation of the different sources into the TMDL are defined in the following equation:

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{MOS} \qquad [9.1]$$

where,

WLA = wasteload allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety.

While developing allocation scenarios to implement the bacteria TMDL, an implicit margin of safety (MOS) was used by using conservative estimations of all factors that would affect the bacteria loadings in the watershed (e.g., animal numbers, production rates, and contributions to streams). These factors were estimated in such a way as to represent the worst-case scenario; i.e., these factors would describe the worst stream conditions that could exist in the watershed. Creating a TMDL with these conservative estimates ensures that the worst-case scenario has been considered and that no water quality standard violations will occur if the TMDL plan is followed.

The time period selected for the load allocation study was September 1987 to December 2001, a portion of the period for which observed data were available. This period was selected because it covers the period in which water quality violations were observed; it incorporates average rainfall, low rainfall, and high rainfall years; and the climate during this period caused a wide range of hydrologic events including both low and high flow conditions.

The calendar-month geometric mean values used in this report are geometric means of the daily concentrations. Because HSPF was operated with a one-hour time step in this study, 24 hourly concentrations were generated each day. To estimate the calendar-month geometric mean from the hourly HSPF output, we took the arithmetic mean of the hourly values on a daily basis, and then calculated the geometric mean from these average daily values.

The guidance for developing an *E. coli* TMDL offered by VADEQ is to develop input for the model using fecal coliform loadings as the bacteria source in the watershed. Then, VADEQ suggests the use of a translator equation they developed to convert the daily average fecal coliform concentrations output by the model to daily average *E. coli* concentrations. The translator equation is:

$$E.\ coli\ \text{concentration} = 2^{-0.0172} \times (\text{FC concentration}^{0.91905}) \qquad [9.2]$$

where the bacteria concentrations (FC and *E. coli*) are in cfu/100mL.

This equation was used to convert the fecal coliform concentrations output by HSPF to *E. coli* concentrations. Daily *E. coli* loads were obtained by using the *E. coli* concentrations calculated from the translator equation and multiplying them by the average daily flow. Annual loads were obtained by summing the daily loads and dividing by the number of years in the allocation period.

9.1.2. Existing Conditions

Analyses of the simulation results for the existing conditions in the watershed for the 1987 to 2001 allocation period (Table 9.1) show that direct deposition of manure by cattle into the stream is the primary source of *E. coli* in the stream. Direct deposition of manure by cattle into Linville Creek is responsible for approximately 45% of the mean daily *E. coli* concentration. The next largest contributors are NPS loadings from upland pervious land segments (manure applied to cropland, pastures, and forests by livestock, wildlife, and other NPS sources), which is responsible for 31% of the mean daily *E. coli* concentration. Direct deposits to streams by wildlife are responsible for 19% of the mean daily *E. coli* concentration, while straight pipes contribute 6% of the concentration. Runoff from impervious areas contributed less than 1% of the mean daily *E. coli* concentration.

Table 9.1. Relative contributions of different *E. coli* sources to the overall *E. coli* concentration for the existing conditions in the Linville Creek watershed.

Source	Mean Daily *E. coli* Concentration by Source, cfu/100mL	Relative Contribution by Source
All sources	1,075	
Direct deposits of cattle manure to stream	485	45.1%
Nonpoint source loadings from pervious land segments	328	30.5%
Direct nonpoint source loadings to the stream from wildlife	200	18.6%
Straight-pipe discharges to stream	62	5.8%
Nonpoint source loadings from impervious land use	<1	<1%

As shown in Table 9.1, direct *E. coli* loadings by cattle in the stream result in much higher mean daily *E. coli* concentrations (485 cfu/100 mL) than do *E. coli* loadings from pervious upland areas (328 cfu/100 mL). The contribution of each of these sources to the calendar-month geometric *E. coli* concentration is shown in Figure 9.1. As indicated in this figure, the calendar-month geometric mean value is dominated by contributions from direct deposits of cattle to streams, and these deposits alone result in many violations of the calendar-month geometric mean goal of 126 cfu/100mL. In-stream *E. coli* concentrations from direct nonpoint sources, particularly cattle in streams, are highest during the summer when stream flows are lowest. This is expected because cattle spend more time in streams during the summer months; because of the low flow conditions, there is less stream flow for dilution of the direct deposit manure load. The same is true for the direct deposit from wildlife, to a lesser extent. The violations due to direct deposits from wildlife suggest that some reductions in wildlife loadings will be required in the final TMDL allocation. Figure 9.1 also shows that straight pipes and nonpoint source loadings from pervious land segments ("PLS Only") are relatively minor, compared to the other sources. Finally, the calendar-month geometric means for impervious land segments were so low they were not included in Figure 9.1.

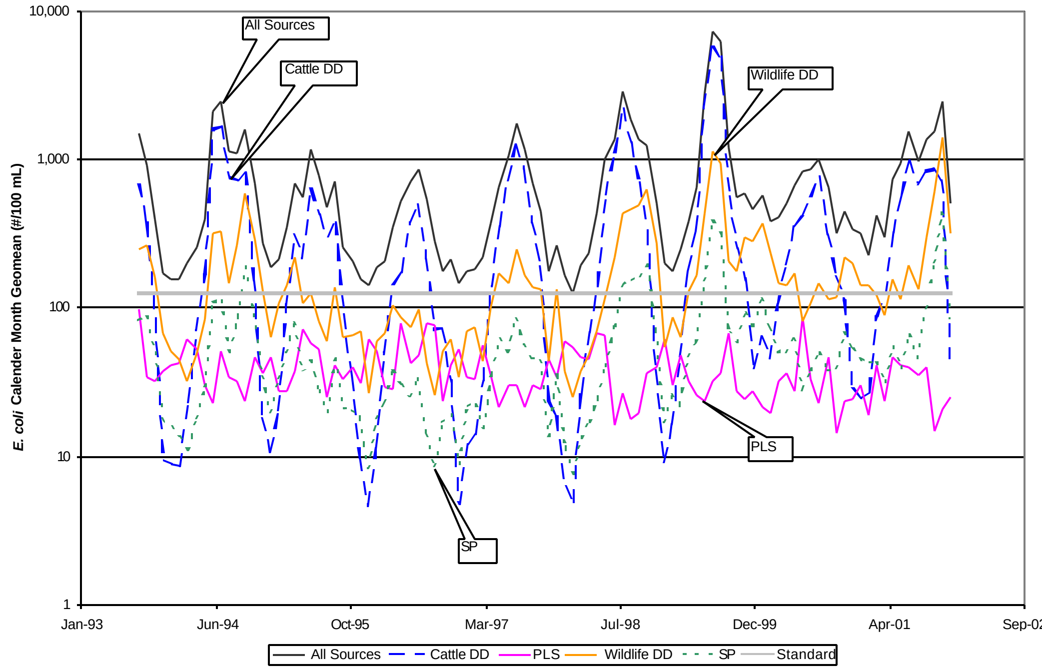


Figure 9.1. Relative contributions of different *E. coli* sources to the calendar-month geometric mean *E. coli* concentration for existing conditions in the Linville Creek watershed.

9.1.3. Waste Load Allocation

Waste load allocations were assigned to each point source facility in the Linville Creek watershed. Point sources were represented in the allocation scenarios (Section 9.1.4) by their current permit conditions; no reductions were required from point sources in the TMDL. Current permit requirements are expected to result in attainment of the *E. coli* WLA as required by the TMDL. Point source contributions, even in terms of maximum flow, are minimal. Therefore, no reasonable potential exists for these facilities to have a negative impact on water quality and there is no reason to modify the existing permits. The point source facilities are discharging at their criteria and therefore cannot cause a violation of the water quality criteria. Note that the *E. coli* WLA value presented in Section 9.1.5 represents the sum of all point source *E. coli* WLAs in Linville Creek.

9.1.4. Allocation Scenarios

A variety of allocation scenarios were evaluated to meet the *E. coli* TMDL goal of a calendar-month geometric mean of 126 cfu/100mL and the single sample limit of 235 cfu/100mL. The scenarios and results are summarized in Table 9.2. Because direct deposition of *E. coli* by cattle into streams was responsible for 45% of the mean daily *E. coli* concentration (Table 9.1) and the vast majority of the calendar-month geometric mean value, all scenarios considered required reductions in or elimination of direct deposits by cattle.

In all scenarios considered in Table 9.2, non-permitted straight-pipe contributions from on-site waste disposal systems were eliminated because these contributions are illegal under existing state law. Nonpoint source contributions from impervious land segments were neglected because their contribution to the calendar-month geometric mean concentration is negligible (Table 9.1). In scenario 01, straight-pipes were eliminated and high reductions (at least 90%) were made in direct deposits by cattle and wildlife to streams, along with large reductions from land surface loads (cropland, pasture, loafing lots, and residential), yet there were still violations of both the calendar-month geometric mean (3%) and single sample (9%) *E. coli* standards (Table 9.2). The same was true for scenarios 02 and 05. Scenarios 03, 04, 06, and 07 all met the calendar-month and single sample *E. coli* standards. Scenario 07 was selected as the TMDL allocation because this scenario had slightly lower reductions required for cropland, pasture, residential areas, and wildlife direct deposit compared to the other scenarios that met the *E. coli* standards. The concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 9.2 for the TMDL allocation (Scenario 07), along with the standards.

Table 9.2. Bacteria allocation scenarios for Linville Creek watershed.

Scenario Number	% Violation of *E. coli* Standard		Fecal Coliform Loading Reduction Required to Meet the *E coli* Standards, %						
	Geomean	Single Sample	Cattle DD	Cropland	Pasture	Loafing Lot	Wildlife DD	Straight Pipes	All Residential PLS
01	3%	9%	99	70	70	95	90	100	50
02	0%	2%	99.9	75	75	99	95	100	75
03	0%	0%	99.9	97	97	99.9	99.9	100	97
04	0%	0%	99.9	97	97	99.9	95	100	97
05	0%	1%	99.5	95	95	99.5	97	99.5	99.5
06	0%	0%	99.5	97	97	99.5	97	99.5	97
07	0%	0%	100	96	96	100	95	100	99

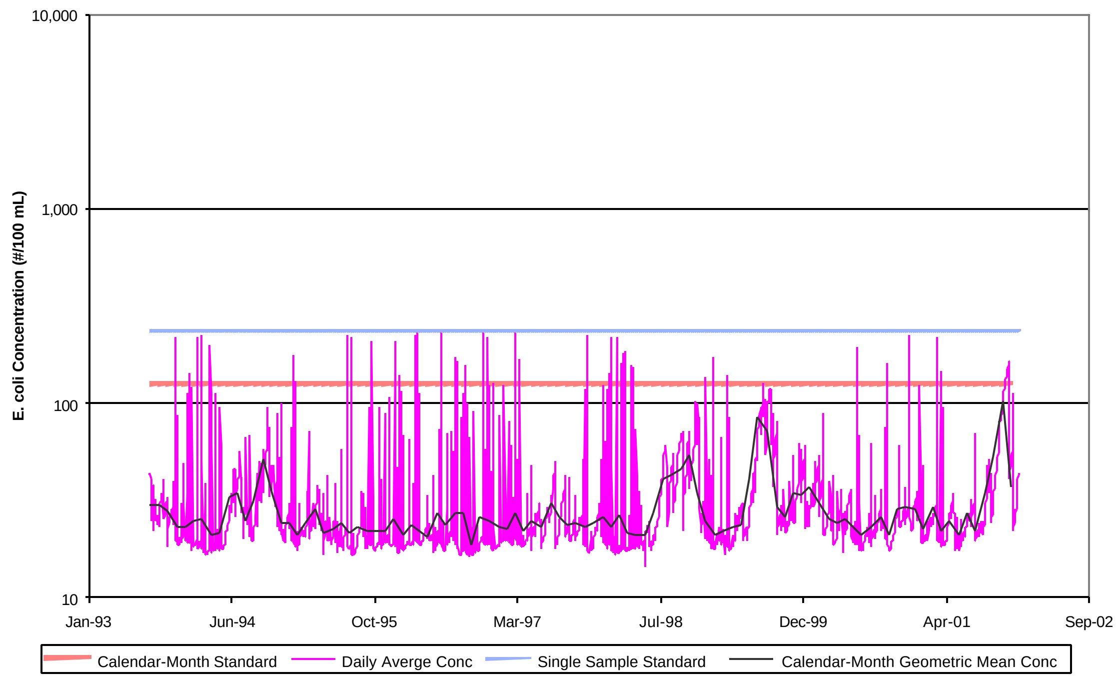


Figure 9.2. Calendar-month geometric mean standard, single sample standard, and successful *E. coli* TMDL allocation (Allocation Scenario 07 from Table 9.2) for Linville Creek.

Loadings for existing conditions and TMDL allocation scenario (Scenario 07) are presented for nonpoint sources by land use in Table 9.3 and for direct nonpoint sources in Table 9.4. It is clear that extreme reductions in both loadings from land surfaces and from sources directly depositing in the streams of Linville Creek are required to meet both the calendar-month geometric mean and single sample standards for *E. coli*. Cattle and wildlife deposition directly in streams dominates the *E. coli* contributions to the stream, particularly during the summer months when cattle spend more time in the stream, flows are lower, and there is minimum dilution due to reduced stream flow. Loadings from upland areas are reduced during these periods because there is little upland runoff to transport fecal coliform to streams. When high flow conditions do occur, however, the large magnitude of the nonpoint source loadings coming from upland areas will result in violations of the water quality standard. Because these upland loadings are intermittent, they are not a primary source of violations of the calendar-month geometric mean standard, but do cause many violations of the *E. coli* single sample standard.

Table 9.3. Annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario (Scenario 07).[a]

Land use Category	Existing Conditions		Allocation Scenario	
	Existing condition load ($\times 10^{12}$ cfu)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load
Cropland	4.31	0.01%	0.17	96%
Pasture	54,654	94.47%	2,186	96%
Residential[b]	932.2	1.61%	9.3	99%
Loafing Lot	2,251.7	3.89%	0	100%
Forest	12.8	0.02%	12.8	0%
Total	57,885	100%	2,208.4	96%

[a] For details on calculation of *E. coli* loads, see Section 9.1.1 and Equation 9.2

[b] Includes loads applied to both High and Low Density Residential and Farmstead

Table 9.4. Annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario (Scenario 07).[a]

Source	Existing Condition		Allocation Scenario	
	Existing condition load ($\times 10^{12}$ cfu)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load
Cattle in streams	98.5	88.58%	0	100%
Straight-Pipes	12.0	10.79%	0	100%
Wildlife in Streams	0.7	0.63%	0.035	95%
Total	111.2	100%	0.035	100%

[a] For details on calculation of *E. coli* loads, see Section 9.1.1 and Equation 9.2

The fecal coliform loads presented in Tables 9.3 and 9.4 are the fecal coliform loads that result in in-stream *E. coli* concentrations that meet the applicable *E. coli* water quality standards after application of the VADEQ fecal coliform to *E. coli* translator to the HSPF predicted mean daily fecal coliform concentrations. The *E. coli* TMDL allocation load for both nonpoint and direct nonpoint sources at the watershed outlet is 2,117.8 x 10^{10} cfu, which requires a fecal coliform upland and direct deposition load reduction of 96% compared to the existing load. The load reductions by sub-watershed are listed in Appendix G.

9.1.5. Summary of TMDL Allocation Scenario for Bacteria

A TMDL for *E. coli* has been developed for Linville Creek. The TMDL addresses the following issues:

1. The TMDL meets the calendar-month geometric mean and single sample water quality standards. After the plan is fully implemented, the calendar-month geometric mean *E. coli* concentration will not exceed 126 cfu/100mL and any no single sample will result in *E. coli* concentrations greater than 235 cfu/100mL.

2. Because *E. coli* loading data were not available to quantify point or nonpoint source bacterial loads, available fecal coliform loading data were

used as input to HSPF. HSPF was then used to simulate in-stream fecal coliform concentrations. The VADEQ fecal coliform to *E. coli* concentration translator was then used to convert the simulated fecal coliform concentrations to *E. coli* concentrations for which the bacteria TMDL was developed.

3. The TMDL was developed taking into account all fecal bacteria sources (anthropogenic and natural) from both point and nonpoint sources.

4. An implicit margin of safety (MOS) was incorporated to ensure compliance of both the geometric mean and single sample standards upon full implementation.

5. Both high- and low-flow stream conditions were considered while developing the TMDL. In the Linville Creek watershed, low stream flow was found to be the environmental condition most likely to cause a violation of the geometric mean; however, because the TMDL was developed using a continuous simulation model, it applies to both high- and low-flow conditions. A graph of the simulated stream flow for the allocation period is provided in Appendix H.

6. Both the flow regime and bacteria loading to Linville Creek are seasonal, with higher loadings and in-stream concentrations during summer. The TMDL accounts for these seasonal effects.

The selected *E. coli* TMDL allocation that meets both the calendar-month geometric mean and single sample water quality goals requires a 100% reduction in direct deposits of cattle manure to streams, elimination of all unpermitted straight-pipe discharges, a 95% reduction in direct deposits by wildlife to streams and a 96% reduction in nonpoint source loadings to the land surface. Using Eq. [9.1], the summary of the bacteria TMDL for Linville Creek for the selected allocation scenario (Scenario 07) is given in Table 9.5. As directed by VADEQ, the TMDL load in Table 9.5 was determined from the average annual

E. coli load at the watershed outlet for the chosen allocation scenario over the simulation period. In Table 9.5, the WLA was obtained by summing the products of each permitted point source's fecal coliform discharge concentration and allowable annual discharge. The LA is then determined as the TMDL – WLA.

Table 9.5. Average annual *E. coli* loadings (cfu/year) at the watershed outlet used for the Linville Creek bacteria TMDL.

Pollutant	SWLA	SLA	MOS	TMDL
E. coli	11.0 x 10^{10} *(VA0085588 = 5.22*10^{10} SSFH WLA = 5.74*10^{10})*	2,106.8 x10^{10}	NA	2,117.8x10^{10}

NA – Not Applicable because MOS was implicit

9.2. Sediment TMDL

9.2.1. Background

The sediment TMDL for the Linville Creek watershed was developed using a reference watershed approach, with the Upper Opequon Creek watershed as the reference. Loads are shown in metric tons (t) and area in hectares (ha). The GWLF model was calibrated for hydrology separately for each watershed and then run for existing conditions over the 10-yr period, January 1988 – December 1997. The sediment load from the reference watershed was used to define the sediment TMDL load for the impaired Linville Creek watershed. Because the watersheds varied slightly in total area, sediment load comparisons were based on a watershed unit area load (t/ha) basis, and were calculated as the 10-yr average annual unit load (t/ha-yr).

9.2.2. Existing Conditions

The existing sediment loads were modeled for each watershed and are listed in Table 9.6 by land use category, percent of total watershed load, and sediment load unit area loads for individual land uses.

Table 9.6. Existing Sediment Loads

Surface Runoff Sources	Linville Creek (t/yr)	(%)	(t/ha-yr)	Upper Opequon Creek (t/yr)	(%)	(t/ha-yr)
High Till	14,014.3	39.5%	30.5	12,286.6	28.4%	20.9
Low Till	6,178.0	17.4%	13.4	4,138.3	9.6%	9.2
Hay	3,048.9	8.6%	1.1	2,263.2	5.2%	1.3
Pasture	5,360.0	15.1%	1.1	3,150.8	7.3%	0.6
Manure Acres	0.0	0.0%	0.0	0.0	0.0%	0.0
Forest	144.3	0.4%	0.0	204.7	0.5%	0.1
Disturbed Forest	158.7	0.4%	13.1	4,374.0	10.1%	15.9
Pervious Urban	54.6	0.2%	0.2	190.5	0.4%	0.1
Impervious Urban	77.8	0.2%	0.5	228.4	0.5%	0.2
Other Sources						
Channel Erosion	6,407.1	18.1%		16,412.2	37.9%	
Point Sources	1.6	0.0%		11.4	0.0%	
Watershed Totals						
Existing Sediment Load (t/yr)	35,445.2			43,260.0		
Area (ha)	12,015.2			15,044.5		
Unit Area Load (t/ha-yr)	2.950			**2.875**		
Target Sediment TMDL Load	**34,549.3**	**t/yr**				

The sediment TMDL for Linville Creek is the sum of the three required components, given previously in equation 9.1, and quantified in Table 9.7.

Table 9.7. Linville Creek Sediment TMDL (t/yr)

TMDL	WLA	LA	MOS
34,549.3	5.5	31,088.8	3,454.9
	VA0085588 = 1.2455		
	VA0079898 = 2.9016		
	? SFH WLA = 1.3679		

The TMDL was calculated as the watershed-based unit area load for the Upper Opequon Creek (2.875 t/ha-yr) multiplied by the area of the Linville Creek watershed (12,015.2 ha). The margin of safety (MOS) was explicitly modeled as 10% of the calculated TMDL to reflect the relative increase in uncertainty, compared to the MOS of 5% typically used in other TMDLs for the more complex modeling of fecal coliform. The waste load allocation (WLA) was included as the sum of all contributions from specifically permitted point sources, as well as those 1000 gpd units covered under the general permit. The load allocation (LA) – the allowable sediment load from nonpoint sources – was calculated as the TMDL minus the MOS minus the WLA.

Changes in future land use distribution and sediment sources were judged to be minimal, and were modeled as constant. The TMDL was based, therefore, on existing land uses and sediment sources.

9.2.3. Waste Load Allocation

Waste load allocations were assigned to each point source facility in the Linville Creek watershed. Point sources were represented in the allocation scenarios (Section 9.2.4) by their current permit conditions; no reductions were required from point sources in the TMDL. Current permit requirements are expected to result in attainment of the sediment WLA as required by the TMDL. Point source contributions, even in terms of maximum flow, are minimal (<0.1%), and can be viewed as insignificant. Therefore, no reasonable potential exists for these facilities to have a negative impact on water quality and there is no reason to modify the existing permits. Note that the sediment WLA value presented in Section 9.2.5 represents the sum of all point source sediment WLAs in Linville Creek.

9.2.4. Allocation Scenarios

For development of the allocation scenarios, sediment sources were grouped into the following four categories: Agriculture, Urban, Channel Erosion, and Point Sources. Because all Point Source sediment loads are permitted, and because Urban sources contributed an insignificant amount of sediment (< 1%), no reductions were taken from these two categories. All allocation scenarios were developed, therefore, with reductions from the Agriculture and Channel Erosion categories.

Three alternative allocation scenarios were developed, as quantified in Table 9.8.

Table 9.8. Alternative Load Reduction Scenarios.

Source Category	Existing (t/yr)	Linville Creek TMDL Sediment Load Allocations					
		TMDL Scenario 1		TMDL Scenario 2		TMDL Scenario 3	
		(% reduction)	(t/yr)	(% reduction)	(t/yr)	(% reduction)	(t/yr)
Agriculture	28,904.2	**15.1**	24,549.5	**12.3**	25,339.7	**9.6**	26,125.7
Urban	132.4	0.0	132.4	0.0	132.4	0.0	132.4
Channel Erosion	6,407.1	0.0	6,407.1	12.3	5,617.0	24.6	4,831.0
Point Sources	1.4		5.3		5.3		5.3
Total	**35,445.0**	12.3	31,094.4	12.3	31,094.4	12.3	31,094.4

These three scenarios are defined as follows:

1. TMDL Scenario 1 takes all of the reductions from the largest source category – Agriculture.

2. TMDL Scenario 2 takes equal percent reductions from Agriculture and Channel Erosion.

3. Because Channel Erosion includes streambank erosion from livestock with access to streams, and because the companion bacteria TMDL for Linville Creek calls for reductions in livestock access, TMDL Scenario 3 accounts for the sediment reduction due to restricting livestock access to streams at the level called for in the bacteria TMDL, and then takes the remaining reduction needed to meet the TMDL from Agriculture. The reduction in Channel Erosion was calculated as follows:

$$\text{Channel Erosion \% reduction} = A * B * C \qquad [9.3]$$

where A = % of total stream length with livestock access (49.2%);

B = % reduction in “Livestock Access” for the Bacteria TMDL (100%); and

C = % sediment reduction efficiency of restricting livestock access (50%).

9.2.5. Summary of TMDL Allocation Scenario for Sediment

Two sediment source categories in the watershed – Agriculture and Channel Erosion – were responsible for the majority of the sediment load in Linville Creek. The sediment TMDL for Linville Creek is 34,549 t/yr and will require an overall reduction of 12.3% from existing loads. From the three alternative scenarios explored, Scenario 3 is recommended because it coordinates with reductions called for in the companion bacteria TMDL.

The Linville Creek sediment TMDL was developed to meet the sediment unit area load of a selected reference watershed – Upper Opequon Creek. The TMDL was developed to take into account all sediment sources in the watershed from both point and nonpoint sources. The sediment loads were averaged over a 10-year period to take into account both wet and dry periods in the hydrologic cycle, and the model inputs took into consideration seasonal variations and critical conditions related to sediment loading. An explicit 10% margin of safety was added into the final TMDL load calculation.

CHAPTER 10: TMDL IMPLEMENTATION AND REASONABLE ASSURANCE

The goal of this TMDL is to establish a three-step path that will lead to attainment of water quality standards in the Goose Creek watershed. The first step in the process was to develop a TMDL that will result in Linville Creek meeting water quality standards. This report represents the culmination of that effort. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL, monitor water quality, and determine if water quality standards are being attained.

Upon EPA approval of the TMDLs, VADEQ intends to incorporate them into the appropriate Water Quality Management Plan (WQMP), in accordance with the CWA's Section 303(e). VADEQ submitted a Continuous Planning Process to EPA that commits to regularly updating the WQMPs. Thus, the WQMPs will become the repository for all TMDLs and TMDL implementation plans developed within a river basin.

Section 303(d) of the Clean Water Act (CWA) and current EPA regulations do not require the development of implementation strategies. However, including implementation plans as a TMDL requirement has been discussed for future federal regulations. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQ MIRA) directs VADEQ in section 62.1-44.19.7 to "develop and implement a plan to achieve fully supporting status for impaired waters". The WQ MIRA also establishes that the implementation plan shall include the date of expected achievement of water quality objectives; measurable goals; corrective actions necessary; and the associated cost, benefits, and environmental impact of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, time line, legal or regulatory controls, time required to attain water quality standards, monitoring plan, and milestones for attaining water quality standards. Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of VADEQ, VADCR, and other cooperating agencies. A guidance document will also be available from DEQ and DCR to help citizens understand and participate in the TMDL implementation process.

10.1. Reasonable Assurance Using Phased Implementation

In general, the Commonwealth intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, the most promising management practice in agricultural areas of the watershed is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both from the cattle deposits themselves and from additional buffering in the riparian zone. Additionally, reducing the human bacteria loading from failing septic systems should be a primary focus because of its health implications. This component could be implemented through education on septic pump-outs as well as a septic system inspection and management program.

Implementation of the TMDLs for Linville Creek and its tributaries will occur in stages. The benefits of phased implementation are:

1. as stream monitoring continues, water quality improvements can be recorded as they are achieved;

2. it provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;

3. it provides a mechanism for developing public support;

4. it helps ensure that the most cost effective practices are implemented first; and

5. it allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

10.2. Phase 1 Implementation Scenario for Linville Creek

The goal of the Phase 1 Implementation Scenario was to determine the *E. coli* loading reductions required to reduce violations of the single sample 235 cfu/100mL water quality standard to less than 10 percent. For the implementation scenarios, HSPF was run with a 1-hour time step, as with the TMDL allocation scenarios. A margin of safety was not used in determining the Phase 1 Implementation Scenario. Several scenarios reduced violations to less than 10% (Table 10.1).

The final scenario selected for Phase 1 implementation (Scenario 07) requires a 99% reduction in direct deposits by cattle to streams, reductions (70%) in loadings from cropland and pastures, and elimination of all straight-pipes. No reduction in wildlife deposits to the stream is required. A 95% reduction in loafing lot loads is required along with a 50% reduction in loads from residential areas. Fecal coliform loadings for the existing allocation and Phase 1 allocation scenario for nonpoint sources by land use are presented in

Table 10.2 and for direct nonpoint sources in

Table 10.3. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the Scenario 07 fecal coliform loads are presented graphically in Figure 10.1.

The reductions in agriculture and livestock access to streams required from the bacteria TMDL phase 1 implementation scenario will reduce the sediment loads to a level below those required for the final sediment TMDL. Therefore, the phase 1 implementation plan for sediment is the same as that for bacteria.

Table 10.1. Allocation scenarios for Phase 1 TMDL implementation for Linville Creek.

Scenario Number	Single Sample % Violation	% Reduction Required						
		Cattle DD	Cropland	Pasture	Loafing Lot	Wildlife DD	Straight Pipes	All Residential PLS
01	9	99	70	70	95	90	100	50
02	9	99	60	60	95	90	100	50
03	13	99	60	60	95	75	100	50
04	14	99	70	70	95	70	100	50
05	28	99	50	50	99	20	100	50
06	9	99	70	70	95	90	100	50
07	35	99	70	70	95	0	100	50

Table 10.2. Annual nonpoint source load reductions for Phase 1 TMDL implementation scenario for Linville Creek watershed (Scenario 07).

Land use Category	Existing Conditions		Allocation Scenario	
	Existing load ($\times 10^{12}$ cfu)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load
Cropland	4.31	0.01%	1.29	70%
Pasture	54,654	94.47%	16,396	70%
Residential[b]	932.2	1.61%	466	50%
Loafing Lot	2,251.7	3.89%	112	95%
Forest	12.8	0.02%	12.8	0%
Total	57,885	100%	16,988	71%

[a] Includes loads applied to both High and Low Density Residential and Farmstead

[b] Reduction only applies to Low Density Residential and Farmstead Areas (Not to High Density Residential Areas because the loadings from these areas were considered negligible)

Table 10.3. Required direct nonpoint source fecal coliform load reductions for Phase 1 Implementation Scenario (Scenario 07).

Source	Existing Condition		Allocation Scenario	
	Existing condition load ($\times 10^{12}$ cfu)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load
Cattle in streams	98.5	88.58%	0.98	99%
Straight-Pipes	12.0	10.79%	0	100%

Wildlife in Streams	0.7	0.63%	0.7	0%
Total	111.2	100%	1.68	98.5%

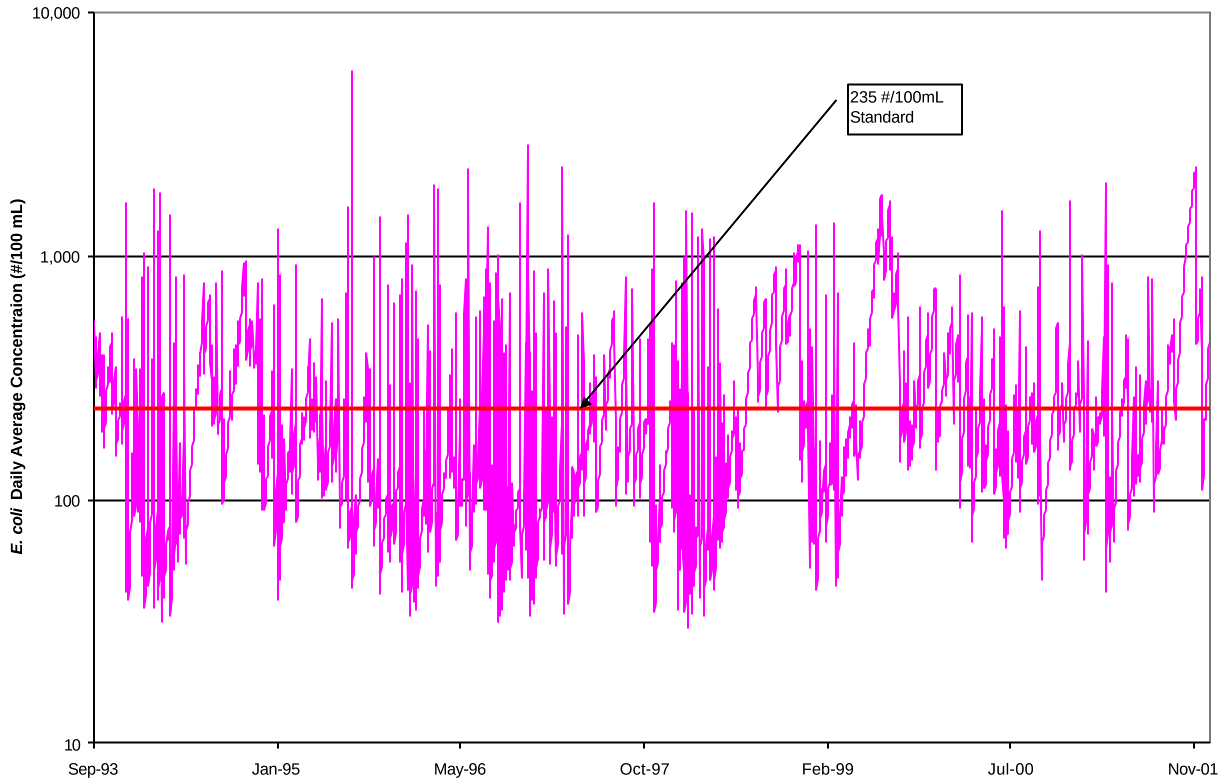


Figure 10.1. Phase 1 TMDL implementation scenario for Linville Creek.

10.3. Follow-up Monitoring

VADEQ will continue to monitor Linville Creek and its tributaries in accordance with its ambient monitoring program. VADEQ and VADCR will continue to use data from these monitoring stations for evaluating reductions in bacteria counts and the effectiveness of the TMDLs in attainment of water quality standards. Sampling under the rotating basin approach will be suspended until an implementation plan has been developed and implementation measures have begun in the watershed. Ambient sampling includes field parameters, bacteria, nutrients and solids. Bacteria sampling will include both fecal coliform and *E. coli*.

10.4. Potential Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the CWA. In response to the federal Clean Water Action Plan, Virginia developed a Unified Watershed Assessment that identifies watershed priorities. Watershed restoration activities, such as TMDL implementation, within these priority watersheds are eligible for Section 319 funding. Increases in Section 319 funding in future years will be targeted toward TMDL implementation and watershed restoration. Additional funding sources for implementation include the USDA Conservation Reserve Enhancement Program (CREP), the Virginia state revolving loan program, and the Virginia Water Quality Improvement Fund.

10.5. Current Efforts to Control Bacteria

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, with support from regional and local offices of VADEQ, VADCR, and other participating agencies. Many efforts are planned or are underway that will help reduce bacteria and sediment loads to Linville Creek. For example, implementation of these TMDLs will contribute to ongoing water quality improvement efforts aimed at restoring water quality in the Chesapeake Bay. Several BMPs known to be effective in controlling bacteria and sediment have also been identified for implementation as part of the 2001 Interim Nutrient Cap Strategy for the Shenandoah/Potomac basin. For example, management of on-site waste management systems, management of livestock and manure, and pet waste management are among the components of the strategy described under nonpoint source implementation mechanisms. New tributary strategies are currently being developed and can be integrated with a TMDL implementation plan for Linville Creek.

10.6. Addressing Wildlife Contributions

In some streams for which TMDLs have been developed, water quality modeling indicates that even after removal of all of the sources of fecal coliform (other than wildlife), the stream will not attain standards. As is the case for Linville Creek, TMDL allocation reductions of this magnitude are not realistic and do not meet EPA's guidance for reasonable assurance. Based on the water quality modeling results, many of these streams will not be able to attain standards without some reduction in wildlife. ***Virginia and EPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards.*** This is obviously an impractical action. While managing over-populations of wildlife remains as an option to local stakeholders, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL. In such a case, after demonstrating that the source of fecal contamination is natural and uncontrollable by effluent limitations and BMPs, the state may decide to re-designate the stream's use for secondary contact recreation or to adopt site-specific criteria based on natural background levels of bacteria. The state must demonstrate that the source of fecal contamination is natural and uncontrollable by effluent limitations and BMPs through a so-called Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted as amendments to the water quality standards regulations. Watershed stakeholders and EPA will be able to provide comment during this process.

The State Water Control Board recently adopted bacteria criteria applicable to any waters that are designated for secondary contact recreation. As proposed, the definition for secondary contact recreation means "a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of waters (examples include but are not limited to wading, boating, and fishing)." This proposed standard will become effective pending EPA approval.

While the proposal set up criteria for protection of secondary contact recreation, no waters have yet been re-designated as such. The re-designation of the current swimming use in a stream to a secondary contact recreational use would require the completion of a Use Attainability Analysis (UAA). A UAA is a structured scientific assessment of the factors affecting the attainment of the use, which may include physical, chemical, biological, and economic factors as described in the Federal Regulations. The stakeholders in the watershed, Virginia, and EPA will have an opportunity to comment on these special studies.

Based on the above, EPA and Virginia have developed a TMDL strategy to address the wildlife issue. The first step in this strategy is to develop an interim reduction goal such as in Table 10.1. The pollutant reductions for the interim goal are applied only to controllable, anthropogenic sources identified in the TMDL, setting aside any control strategies for wildlife. During the first implementation phase, all controllable sources would be reduced to the maximum extent practicable using the staged approach outlined above. Following completion of the first phase, VADEQ would re-assess water quality in the stream to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, a UAA may be initiated to reflect the presence of naturally high bacteria levels due to uncontrollable sources. In some cases, the effort may never have to go to the second phase because the water quality standard violations attributed to wildlife in the model are very small and infrequent and may fall within the margin of error.

Re-designation of the swimming use for secondary contact would only be considered after TMDL implementation measures to achieve compliance with the primary contact standard have been implemented without success and one or more of the following conditions exist:

1. naturally occurring pollutant concentrations prevent the attainment of the use;

2. natural, ephemeral, intermittent, or low flow conditions or water levels prevent the attainment of the use unless these conditions may be compensated for by the discharge of sufficient volume of

effluent discharge without violating state water conservation requirements to enable the uses to be met;

3. human caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place;

4. dams, diversions, or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the waterbody to its original condition or to operate such modification in a way that would result in the attainment of the use;

5. physical conditions related to the natural features of the waterbody, such as the lack of a proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life protection uses; or

6. controls more stringent than those required by Sections 301(b) and 306 of the Clean Water Act would result in substantial and widespread economic and social impact.

CHAPTER 11: PUBLIC PARTICIPATION

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. In May of 2002, members of the Virginia Tech TMDL group traveled to Rockingham County to become acquainted with the watershed. During that trip, they spoke with various stakeholders. In addition, personnel from Virginia Tech, the Headwaters Soil and Water Conservation District (SWCD), and the Natural Resource Conservation Service (NRCS) visited some watershed residents and contacted others via telephone to acquire their input.

The first public meeting was public noticed on September 9, 2002 and held on September 26, 2001, at the Linville-Edom Elementary School in Linville, Virginia to inform the stakeholders of TMDL development process and to obtain feedback on animal numbers in the watershed, fecal production estimates, and to discuss the hydrologic calibration. Copies of the presentation materials and diagrams outlining the development of the TMDL were available for public distribution at the meeting. Approximately 25 people attended the meeting. The public comment period ended on October 25, 2002.

The final public meeting was public noticed on February 24, 2003 and held on March 5, 2003 at the Broadway High School in Broadway, Virginia to present the draft TMDL report and solicit comments from stakeholders. Approximately 40 people attended the final meeting. Copies of the presentation materials were distributed to the public at the meeting. The public comment period ended on April 2, 2003. A summary of the questions and answers discussed at the meeting was prepared and is located at the VADEQ Valley Regional Office in Harrisonburg, VA.

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APPENDIX A

Glossary of Terms

Glossary of Terms

Allocation
That portion of a receiving water's loading capacity that is attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources.

Allocation Scenario
A proposed series of point and nonpoint source allocations (loadings from different sources), which are being considered to meet a water quality planning goal.

Background levels
Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering and dissolution.

BASINS (Better Assessment Science Integrating Point and Nonpoint Sources)
A computer-run tool that contains an assessment and planning component that allows users to organize and display geographic information for selected watersheds. It also contains a modeling component to examine impacts of pollutant loadings from point and nonpoint sources and to characterize the overall condition of specific watersheds.

Best Management Practices (BMP)
Methods, measures, or practices that are determined to be reasonable and cost-effective means for a land owner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

Bacteria Source Tracking
A collection of scientific methods used to track sources of fecal coliform.

Calibration
The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.

Die-off (of fecal coliform)
Reduction in the fecal coliform population due to predation by other bacteria as well as by adverse environmental conditions (e.g., UV radiation, pH).

Direct nonpoint sources
Sources of pollution that are defined statutorily (by law) as nonpoint sources that are represented in the model as point source loadings due to limitations of the model. Examples include: direct deposits of fecal material to streams from livestock and wildlife.

E-911 digital data

Emergency response database prepared by the county that contains graphical data on road centerlines and buildings. The database contains approximate outlines of buildings, including dwellings and poultry houses.

Failing septic system

Septic systems in which drain fields have failed such that effluent (wastewater) that is supposed to percolate into the soil, now rises to the surface and ponds on the surface where it can flow over the soil surface to streams or contribute pollutants to the surface where they can be lost during storm runoff events.

Fecal coliform

A type of bacteria found in the feces of various warm-blooded animals that is used as indicator of the possible presence of pathogenic (disease causing) organisms.

Geometric mean

The geometric mean is simply the nth root of the product of n values. Using the geometric mean, lessens the significance of a few extreme values (extremely high or low values). In practical terms, this means that if you have just a few bad samples, their weight is lessened.

Mathematically the geometric mean, $\bar{x}_g$, is expressed as:

$$\bar{x}_g = \sqrt[n]{x_1 \cdot x_2 \cdot x_3 \ldots \cdot x_n}$$

where n is the number of samples, and x_i is the value of sample i.

HSPF (Hydrological Simulation Program-Fortran)

A computer-based model that calculates runoff, sediment yield, and fate and transport of various pollutants to the stream. The model was developed under the direction of the U.S. Environmental Protection Agency (EPA).

Hydrology

The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Instantaneous criterion

The instantaneous criterion or instantaneous water quality standard is the value of the water quality standard that should not be exceeded at any time. For example, the Virginia instantaneous water quality standard for fecal coliform is 1,000 cfu/100 mL. If this value is exceeded at any time, the water body is in violation of the state water quality standard.

Load allocation (LA)

The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background.

Margin of Safety (MOS)

A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody. The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models). The MOS may also be assigned explicitly, as was done in this study, to ensure that the water quality standard is not violated.

Model

Mathematical representation of hydrologic and water quality processes. Effects of Land use, slope, soil characteristics, and management practices are included.

Nonpoint source

Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

Pathogen

Disease-causing agent, especially microorganisms such as bacteria, protozoa, and viruses.

Point source

Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollution

Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

Reach

Segment of a stream or river.

Runoff

That part of rainfall or snowmelt that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

Septic system

An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives liquid and solid wastes from a residence or business and a drainfield or subsurface absorption system consisting of a series of tile or percolation lines for disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.

Simulation

The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.

Straight pipe

Delivers wastewater directly from a building, e.g., house, milking parlor, to a stream, pond, lake, or river.

Total Maximum Daily Load (TMDL)

The sum of the individual wasteload allocations (WLA's) for point sources, load allocations (LA's) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Urban Runoff

Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Validation (of a model)

Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical process under investigation.

Wasteload allocation (WLA)

The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation.

Water quality standard

Law or regulation that consists of the beneficial designated use or uses of a water body, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular water body, and an anti-degradation statement.

Watershed
A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

For more definitions, see the Virginia Cooperative Extension publications available online:

Glossary of Water-Related Terms. Publication 442-758.
http://www.ext.vt.edu/pubs/bse/442-758/442-758.html

and

TMDLs (Total Maximum Daily Loads) - Terms and Definitions. Publication 442-550.
http://www.ext.vt.edu/pubs/bse/442-550/442-550.html

APPENDIX B

Sample Calculation of Dairy Cattle
(Sub Watershed B46-02)

Sample Calculation: Distribution of Dairy Cattle

(Sub watershed (B46-02) during January)

(Note: Due to rounding, the numbers may not add up.)

Breakdown of the dairy herd is 208 milk cows, 17 dry cows, and 206 heifers.

1. During January, milk cows are confined 75% of the time (Table 4.6). Dry cows and heifers are confined 40% of the time.

Milk cows in confinement	=	208 * (75%)	=	156
Dry cows in confinement	=	17 * (40%)	=	6.8
Heifers in confinement	=	206 * (40%)	=	82.4

2. When not confined, dairy cows are on the pasture or in the stream.

Milk cows on pasture and in the stream	=	(208 – 156)	=	52
Dry cows on pasture and in the stream	=	(17 - 6.8)	=	10.2
Heifers on pasture and in the stream	=	(206-82.4)	=	123.6

3. Fifteen percent of the pasture acreage has stream access (Table 4.7) (recall dairy cows are assumed to graze only on Pasture 1). Hence dairy cattle with stream access are calculated as:

Milk cows on pastures with stream access	=	52 * (15%)	=	7.8
Dry cows on pastures with stream access	=	10.2 * (15%)	=	1.5
Heifers on pastures with stream access	=	123.6 * (15%)	=	18.5

4. Dairy cattle in and around the stream are calculated using the numbers in Step 3 and the number of hours cattle spend in the stream in January (Table 4.6) as:

Milk cows in and around streams	=	7.8 * (0.5/24)	=	0.16
Dry cows in and around streams	=	1.5 * (0.5/24)	=	0.03
Heifers in and around streams	=	18.5 * (0.5/24)	=	0.39

5. Number of cattle defecating in the stream is calculated by multiplying the number of cattle in and around the stream by 30% (Section 4.2.1).

Milk cows defecating in streams	=	0.16 * (30%)	=	0.05
Dry cows defecating in streams	=	0.03 * (30%)	=	0.01
Heifers defecating in streams	=	0.39 * (30%)	=	0.12

6. After calculating the number of cattle defecating in the stream, the number of cattle defecating on the pasture is calculated by subtracting the number of cattle defecating in the stream (Step 5) from number of cattle in pasture and stream (Step 2).

Milk cows defecating on pasture	=	(52 – 0.05)	=	51.95
Dry cows defecating on pasture	=	(10.2 – 0.01)	=	10.19
Heifers defecating on pasture	=	(123.6 – 0.12)	=	123.48

APPENDIX C

Die-off Fecal Coliform During Storage

Die-off of Fecal Coliform During Storage

The following procedure was used to calculate amount of fecal coliform produced in confinement in dairy manure applied to cropland and pasture. All calculations were performed on spreadsheet for each sub watershed with dairy operations in a watershed.

1. It was determined from the producer survey that 15% of the dairy farms had dairy manure storage for less than 30 days; 10% of the dairy farms had storage capacities of 60 days, while the remaining operations had 180-day storage capacity. Using a decay rate of 0.375 (Section 5.5.2) for liquid dairy manure, the die-off of fecal coliform in different storage capacities at the ends of the respective storage periods were calculated using Eq. [5.1]. Based on the fractions of different storage capacities, a weighted average die-off was calculated for all dairy manure.

2. Based on fecal coliform die-off, the surviving fraction of fecal coliform at the end of storage period was estimated to be 0.0078 in dairy manure.

3. The annual production of fecal coliform based on 'as-excreted' values (Table 4.1) was calculated for dairy manure.

4. The annual fecal coliform production from dairy manure was multiplied by the fraction of surviving fecal coliform to obtain the amount of fecal coliform that was available for land application on annual basis. For monthly application, the annual figure was multiplied by the fraction of dairy applied during that month based on the application schedule given in Table 4.10.

APPENDIX D

Weather Data Preparation

Weather Data Preparation

A weather data file for providing the weather data inputs into the HSPF Model was created for the period September 1984 through December 2001 using the WDMUtil. Raw data required for creating the weather data file included hourly precipitation (in.), average daily temperatures (maximum, minimum, and dew point) (°F), average daily wind speed (mi./h), total daily solar radiation (langleys), and percent sun. The primary data source was the National Climatic Data Center's (NCDC) Cooperative Weather Station at Dale Enterprise, Rockingham Co., Virginia; data from three other NCDC stations were also used. Locations and data periods fro the stations used are listed in Table D-1. Daily solar radiation data was generated using WDMUtil. The raw data required varying amounts of preprocessing prior to input into WDMUtil or within WDMUtil to obtain the following hourly values: precipitation (PREC), air temperature (ATEM), dew point temperature (DEWP), solar radiation (SOLR), wind speed (WIND), potential evapotranspiration (PEVT), potential evaporation (EVAP), and cloud cover (CLOU). The final WDM file contained the above hourly values as well as the raw data. Weather data in the variable length format were obtained from the NCDC's weather stations in Dale Enterprise, VA (Lat./Long. 38.5N/78.9W, elevation 1400 ft); Timberville, VA (Lat./Long. 38.7N/78.7W, elevation 1001 ft); Lynchburg Airport, VA (Lat./Long. 37.3N/79.2W, elevation 940 ft); and Elkins Airport, WV (Lat./Long. 38.9N/79.9W, elevation 1948 ft). While deciding on the period of record for the weather WDM file, availability of flow and water quality data was considered in addition to the availability and quality of weather data. Given these considerations, the weather WDM file was prepared for the period of September 1984 through December 2001.

Table D.1. Meteorological data sources.

Type of Data	Location	Source	Recording Frequency	Period of Record	Latitude Longitude
Rainfall (in)	Dale Enterprise	NCDC	1 Hour1 Day	1/1/73 – 12/31/998/1/48 – 12/31/01	38°10'52" 79°05'25"
Rainfall (in)	Timberville, VA	Local Resident	1 Day	1/1/84 – 12/31/01	38°10'52" 79°05'25"
Min Air Temp (°F)	Staunton Sewage Treatment Plant	NCDC	1 Day	8/1/48 – 12/31/01	38°10'52" 79°05'25"
Max Air Temp (°F)	Staunton Sewage Treatment Plant	NCDC	1 Day	8/1/48 – 12/31/01	38°10'52" 79°05'25"
Min Air Temp (°F)	Dale Enterprise	NCDC	1 Day	8/1/48 – 12/31/01	38°27'19" 78°56'07"
Max Air Temp (°F)	Dale Enterprise	NCDC	1 Day	8/1/48 – 12/31/01	38°27'19" 78°56'07"
Cloud Cover (%)	Lynchburg Regional Airport	NCDC	1 Hour	8/1/48 – 12/31/01	37°20'15" 79°12'24"
Dew Point Temp (°F)	Lynchburg Regional Airport	NCDC	1 Hour	1/1/48 – 12/31/01	37°20'15" 79°12'24"
Wind Speed (360° and knots)	Elkins-Randolph Elkins WV	NCDC	1 Hour	1/1/64 – 12/31/01	38°53'07" 79°51'10"

APPENDIX E

Fecal Coliform Loading in Sub-Watersheds

Table E.1. Monthly nonpoint fecal coliform loadings in sub-watershed B46-01.

Month	Fecal Coliform loadings ($x10^8$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	20	469,645	74,398	17,961	242	22,202
Feb.	19	485,606	68,501	19,179	221	20,233
Mar.	20	838,412	78,895	35,950	242	22,202
Apr.	20	831,612	76,597	35,777	234	21,486
May	20	880,244	79,405	37,990	242	22,202
Jun.	20	871,445	77,083	37,721	234	21,486
Jul.	20	921,538	79,909	40,004	242	22,202
Aug.	20	942,582	80,166	41,031	242	22,202
Sep.	20	933,225	77,836	40,734	234	21,486
Oct.	20	632,715	76,387	25,916	242	22,202
Nov.	20	638,008	74,236	26,333	234	21,486
Dec.	20	453,837	74,205	17,190	242	22,202
Total	239	8,898,869	917,618	375,786	2,851	261,594

[1] Includes Farmstead, Low and High Density Residential Loads

Table E.2. Monthly nonpoint fecal coliform loadings in sub-watershed B46-02.

Month	Fecal Coliform loadings ($x10^8$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	753	2,279,048	204,926	84,210	1,210	38,488
Feb.	686	2,295,598	198,570	90,041	1,103	35,074
Mar.	753	4,355,275	280,569	169,308	1,210	38,488
Apr.	728	4,400,586	275,640	168,483	1,171	37,247
May	753	4,625,287	289,083	178,886	1,210	38,488
Jun.	728	4,543,890	283,606	177,445	1,171	37,247
Jul.	753	4,775,102	297,370	188,209	1,210	38,488
Aug.	753	4,854,852	301,681	193,059	1,210	38,488
Sep.	728	4,783,438	296,408	191,847	1,171	37,247
Oct.	753	3,686,252	238,324	121,782	1,210	38,488
Nov.	728	3,556,840	235,954	123,837	1,171	37,247
Dec.	753	2,219,044	201,683	80,561	1,210	38,488
Total	8,869	46,375,212	3,103,814	1,767,668	14,254	453,476

[1] Includes Farmstead, Low and High Density Residential Loads

Table E.3. Monthly nonpoint fecal coliform loadings in sub-watershed B46-03.

Month	Fecal Coliform loadings (x10^8 cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	53	2,329,278	511,601	492,372	952	70,279
Feb.	48	2,421,005	500,121	526,673	868	64,044
Mar.	53	4,237,853	728,484	991,204	952	70,279
Apr.	51	4,204,638	716,745	986,278	921	68,012
May	53	4,451,611	752,775	1,047,073	952	70,279
Jun.	51	4,402,447	739,223	1,037,978	921	68,012
Jul.	53	4,657,870	776,213	1,100,981	952	70,279
Aug.	53	4,766,544	788,563	1,129,385	952	70,279
Sep.	51	4,727,475	776,158	1,122,929	922	68,012
Oct.	53	3,171,138	607,266	712,404	952	70,279
Nov.	51	3,203,736	603,006	724,679	922	68,012
Dec.	53	2,247,428	502,299	470,979	952	70,279
Total	623	44,821,023	8,002,454	10,342,935	11,220	828,042

[1] Includes Farmstead, Low and High Density Residential Loads

Table E.4. Monthly nonpoint fecal coliform loadings in sub-watershed B46-04.

Month	Fecal Coliform loadings (x10^8 cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	240	977,531	189,758	95,857	681	36,413
Feb.	218	1,031,520	193,546	102,516	621	33,183
Mar.	240	1,877,318	321,624	192,817	681	36,413
Apr.	232	1,865,056	318,327	191,801	659	35,239
May	240	1,977,045	336,239	203,563	681	36,413
Jun.	232	1,955,122	331,526	201,507	659	35,239
Jul.	240	2,071,434	350,072	213,735	681	36,413
Aug.	240	2,122,576	357,567	219,246	681	36,413
Sep.	232	2,110,372	354,278	218,236	659	35,239
Oct.	240	1,373,613	247,805	138,538	681	36,413
Nov.	232	1,393,609	249,235	140,999	659	35,239
Dec.	240	938,930	184,101	91,698	681	36,413
Total	2,826	19,694,126	3,434,078	2,010,513	8,023	429,030

[1] Includes Farmstead, Low and High Density Residential Loads

Table E.5. Monthly nonpoint fecal coliform loadings in sub-watershed B46-05.

Month	Fecal Coliform loadings (x10^8 cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	352	4,401,559	624,502	454,930	1,642	68,160
Feb.	321	4,627,203	613,820	486,618	1,496	62,113
Mar.	352	8,342,799	910,560	915,801	1,641	68,160
Apr.	340	8,287,459	896,703	911,258	1,588	65,961
May	352	8,784,370	942,609	967,436	1,641	68,160
Jun.	340	8,696,415	926,386	959,079	1,588	65,961
Jul.	352	9,210,724	973,554	1,017,292	1,641	68,160
Aug.	352	9,435,153	989,844	1,043,536	1,641	68,160
Sep.	340	9,367,301	975,079	1,037,530	1,589	65,961
Oct.	352	6,140,136	750,689	658,231	1,642	68,160
Nov.	340	6,220,517	746,683	669,559	1,589	65,961
Dec.	352	4,232,540	612,235	435,166	1,642	68,160
Total	4,145	87,746,176	9,962,664	9,556,436	19,339	803,075

[1] Includes Farmstead, Low and High Density Residential Loads

Table E.6. Monthly nonpoint fecal coliform loadings in sub-watershed B46-06.

Month	Fecal Coliform loadings (x10^8 cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	345	2,895,102	210,213	338,951	1,901	117,325
Feb.	315	3,096,924	224,854	362,515	1,733	106,917
Mar.	345	5,827,312	423,035	681,830	1,901	117,325
Apr.	334	5,795,508	420,724	678,098	1,839	113,540
May	345	6,149,720	446,436	719,531	1,901	117,325
Jun.	334	6,081,169	441,457	711,502	1,839	113,540
Jul.	345	6,450,304	468,252	754,680	1,901	117,325
Aug.	345	6,616,734	480,332	774,142	1,901	117,325
Sep.	334	6,592,057	478,538	771,243	1,840	113,540
Oct.	345	4,183,857	303,752	489,652	1,901	117,325
Nov.	334	4,260,206	309,291	498,567	1,840	113,540
Dec.	345	2,769,279	201,081	324,238	1,901	117,325
Total	4,066	60,718,172	4,407,965	7,104,949	22,397	1,382,354

Table E.7. Monthly nonpoint fecal coliform loadings in sub-watershed B46-07.

Month	Fecal Coliform loadings (x10^8 cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	229	265,450	149,454	0	137	5,729
Feb.	209	248,592	136,299	0	125	5,221
Mar.	229	308,274	150,116	0	137	5,729
Apr.	221	300,697	145,310	0	132	5,544
May	229	313,166	150,192	0	137	5,729
Jun.	221	305,427	145,383	0	132	5,544
Jul.	229	318,055	150,267	0	137	5,729
Aug.	229	320,502	150,305	0	137	5,729
Sep.	221	312,535	145,493	0	132	5,544
Oct.	229	284,413	149,747	0	137	5,729
Nov.	221	278,200	144,962	0	132	5,544
Dec.	229	263,615	149,426	0	137	5,729
Total	2,696	3,518,926	1,766,954	0	1,612	67,504

[1] Includes Farmstead, Low and High Density Residential Loads

Table E.8. Monthly nonpoint fecal coliform loadings in sub-watershed B46-08.

Month	Fecal Coliform loadings (x10^8 cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	103	201,938	1,161	6,971	152	22,208
Feb.	94	216,017	1,242	7,455	139	20,238
Mar.	103	406,581	2,337	14,027	152	22,208
Apr.	100	404,536	2,325	13,956	147	21,492
May	103	429,446	2,468	14,816	152	22,208
Jun.	100	425,579	2,446	14,682	147	21,492
Jul.	103	451,413	2,595	15,573	152	22,208
Aug.	103	463,061	2,662	15,975	152	22,208
Sep.	100	460,535	2,647	15,887	147	21,492
Oct.	103	292,162	1,679	10,082	152	22,208
Nov.	100	297,238	1,709	10,257	147	21,492
Dec.	103	193,161	1,111	6,668	152	22,208
Total	1,219	4,241,667	24,382	146,349	1,793	261,665

[1] Includes Farmstead, Low and High Density Residential Loads

Table E.9. Monthly nonpoint fecal coliform loadings in sub-watershed B46-09.

Month	Fecal Coliform loadings (x10^8 cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	134	1,301,877	155,012	31,022	586	114,485
Feb.	122	1,363,159	165,812	33,180	534	104,329
Mar.	134	2,634,277	312,087	62,437	586	114,485
Apr.	130	2,651,538	310,570	62,133	567	110,792
May	134	2,803,264	329,750	65,970	586	114,485
Jun.	130	2,769,041	327,063	65,432	567	110,792
Jul.	134	2,925,783	346,916	69,403	586	114,485
Aug.	134	2,990,224	355,866	71,193	586	114,485
Sep.	130	2,961,499	353,678	70,755	567	110,792
Oct.	134	2,044,393	224,351	44,890	586	114,485
Nov.	130	2,017,565	228,168	45,653	567	110,792
Dec.	134	1,253,382	148,277	29,675	586	114,485
Total	1,580	27,716,002	3,257,550	651,743	6,908	1,348,896

[1] Includes Farmstead, Low and High Density Residential Loads

Table E.10. Monthly nonpoint fecal coliform loadings in sub-watershed B46-10.

Month	Fecal Coliform loadings (x10^8 cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	806	3,040,385	452,648	310,851	1,676	122,159
Feb.	734	3,076,694	450,024	332,354	1,528	111,323
Mar.	806	5,810,011	692,822	624,925	1,676	122,159
Apr.	780	5,881,899	683,644	621,990	1,622	118,219
May	806	6,188,557	720,036	660,512	1,676	122,159
Jun.	780	6,090,769	709,494	655,794	1,622	118,219
Jul.	806	6,405,531	746,848	695,574	1,676	122,159
Aug.	806	6,517,267	760,551	713,494	1,676	122,159
Sep.	780	6,420,604	749,790	708,488	1,622	118,219
Oct.	806	4,874,106	558,830	449,704	1,676	122,159
Nov.	780	4,701,950	557,564	457,116	1,622	118,219
Dec.	806	2,956,432	442,351	297,386	1,676	122,159
Total	9,493	61,964,205	7,524,602	6,528,188	19,751	1,439,311

[1] Includes Farmstead, Low and High Density Residential Loads

Table E.11. Monthly nonpoint fecal coliform loadings in sub-watershed B46-11.

Month	Fecal Coliform loadings (x10^8 cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	621	3,854,499	480,296	433,543	1,664	173,712
Feb.	566	3,786,230	497,761	463,499	1,516	158,302
Mar.	621	7,605,929	864,749	871,392	1,663	173,712
Apr.	601	7,816,675	857,983	867,346	1,610	168,108
May	621	8,175,570	908,408	921,115	1,663	173,712
Jun.	601	8,000,201	899,655	914,806	1,610	168,108
Jul.	621	8,366,841	951,587	970,291	1,663	173,712
Aug.	621	8,466,808	973,531	995,283	1,663	173,712
Sep.	601	8,297,408	963,971	988,056	1,610	168,108
Oct.	621	6,999,923	650,339	627,203	1,664	173,712
Nov.	601	6,537,254	656,124	637,452	1,610	168,108
Dec.	621	3,779,424	463,816	414,774	1,664	173,712
Total	7,320	81,686,762	9,168,220	9,104,760	19,599	2,046,719

APPENDIX F
Required Reductions in Fecal Coliform Loads by Sub-Watershed – Allocation Scenario

Table F-1a. Required annual reductions in nonpoint sources in sub watershed B46-01 of the Linville Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	39,985	0.38%	1,599	96%
Pasture[1]	10,192,000	97.10%	407,680	96%
Loafing Lots	0	0.00%	0	100%
Forest	2,851	0.03%	2,851	0%
Residential[2]	261,590	2.49%	2,616	99%
Total	10,496,426	100%	414,746	96%

[1] Includes Pastures 1, 2 and 3

[2] Includes Farmstead, Low and High Density Residential Loads

Table F-1b. Required annual reductions in direct nonpoint sources in sub watershed B46-01 of the Linville Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	6,495	98%	0	100%
Wildlife in stream	127	2%	6	95%
Straight pipes	0	0%	0	0%
Total	6,622	100%	6	100%

Table F-2a. Required annual reductions in nonpoint sources in sub watershed B46-02 of the Linville Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	7,146,059	10.32%	285,842	96%
Pasture[1]	59,988,320	86.64%	2,399,533	96%
Loafing Lots	1,641,230	2.37%	0	100%
Forest	14,254	0.02%	14,254	0%
Residential[2]	445,476	0.64%	4,455	99%
Total	69,235,339	100%	2,704,084	96%

[1] Includes Pastures 1, 2 and 3

[2] Includes Farmstead, Low and High Density Residential Loads

Table F-2b. Required annual reductions in direct nonpoint sources in sub watershed B46-02 of the Linville Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	79,568	96%	0	100%
Wildlife in stream	901	1%	45	95%
Straight pipes	2,744	3%	2,744	0%
Total	83,213	100%	2,789	97%

Table F-3a. Required annual reductions in nonpoint sources in sub watershed B46-03 of the Linville Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	602,194	0.93%	24,088	96%
Pasture[1]	63,166,400	97.77%	2,526,656	96%
Loafing Lots	0	0.00%	0	100%
Forest	11,220	0.02%	11,220	0%
Residential[2]	828,042	1.28%	8,280	99%
Total	64,607,856	100%	2,570,244	96%

[1] Includes Pastures 1, 2 and 3

[2] Includes Farmstead, Low and High Density Residential Loads

Table F-3b. Required annual reductions in direct nonpoint sources in sub watershed B46-03 of the Linville Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	117,308	85%	0	100%
Wildlife in stream	504	0%	25	95%
Straight pipes	19,871	14%	19,871	0%
Total	137,683	100%	19,896	86%

Table F-4a. Required annual reductions in nonpoint sources in sub watershed B46-04 of the Linville Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	1,820,454	5.59%	72,818	96%
Pasture[1]	26,982,590	82.81%	1,079,304	96%
Loafing Lots	3,342,030	10.26%	0	100%
Forest	8,023	0.02%	8,023	0%
Residential[2]	429,030	1.32%	4,290	99%
Total	32,582,127	100%	1,164,435	96%

[1] Includes Pastures 1, 2 and 3

[2] Includes Farmstead, Low and High Density Residential Loads

Table F-4b. Required annual reductions in direct nonpoint sources in sub watershed B46-04 of the Linville Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	76,154	81%	0	100%
Wildlife in stream	543	1%	27	95%
Straight pipes	17,877	19%	17,877	0%
Total	94,574	100%	17,904	81%

Table F-5a. Required annual reductions in nonpoint sources in sub watershed B46-05 of the Linville Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	5,946,674	5.19%	237,867	96%
Pasture[1]	107,859,459	94.09%	4,314,378	96%
Loafing Lots	0	0.00%	0	100%
Forest	19,339	0.02%	19,339	0%
Residential[2]	803,075	0.70%	8,031	99%
Total	114,628,547	100%	4,579,615	96%

[1] Includes Pastures 1, 2 and 3

[2] Includes Farmstead, Low and High Density Residential Loads

Table F-5b. Required annual reductions in direct nonpoint sources in sub watershed B46-05 of the Linville Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	205,916	91%	0	100%
Wildlife in stream	937	0%	47	95%
Straight pipes	19,373	9%	19,373	0%
Total	226,226	100%	19,420	91%

Table F-6a. Required annual reductions in nonpoint sources in sub watershed B46-06 of the Linville Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	3,836,970	4.29%	153,479	96%
Pasture[1]	82,322,900	92.06%	3,292,916	96%
Loafing Lots	1,854,430	2.07%	0	100%
Forest	22,397	0.03%	22,397	0%
Residential[2]	1,382,350	1.55%	13,824	99%
Total	89,419,047	100%	3,482,615	96%

[1] Includes Pastures 1, 2 and 3

[2] Includes Farmstead, Low and High Density Residential Loads

Table F-6b. Required annual reductions in direct nonpoint sources in sub watershed B46-06 of the Linville Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	295,312	93%	0	100%
Wildlife in stream	1,084	0%	54	95%
Straight pipes	19,658	6%	19,658	0%
Total	316,054	100%	19,712	94%

Table F-7a. Required annual reductions in nonpoint sources in sub watershed B46-07 of the Linville Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	7,139	0.13%	286	96%
Pasture[1]	5,285,880	98.58%	211,435	96%
Loafing Lots	0	0.00%	0	100%
Forest	1,612	0.03%	1,612	0%
Residential[2]	67,504	1.26%	675	99%
Total	5,362,135	100%	214,008	96%

[1] Includes Pastures 1, 2 and 3

[2] Includes Farmstead, Low and High Density Residential Loads

Table F-7b. Required annual reductions in direct nonpoint sources in sub watershed B46-07 of the Linville Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	37	20%	0	100%
Wildlife in stream	150	80%	8	95%
Straight pipes	0	0%	0	0%
Total	187	100%	8	96%

Table F-8a. Required annual reductions in nonpoint sources in sub watershed B46-08 of the Linville Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	69,065	1.46%	2,763	96%
Pasture[1]	4,412,400	92.99%	176,496	96%
Loafing Lots	0	0.00%	0	100%
Forest	1,793	0.04%	1,793	0%
Residential[2]	261,665	5.51%	2,617	99%
Total	4,744,923	100%	183,668	96%

[1] Includes Pastures 1, 2 and 3

[2] Includes Farmstead, Low and High Density Residential Loads

Table F-8b. Required annual reductions in direct nonpoint sources in sub watershed B46-08 of the Linville Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	10,626	99%	0	100%
Wildlife in stream	115	1%	6	95%
Straight pipes	0	0%	0	0%
Total	10,741	100%	6	100%

Table F-9a. Required annual reductions in nonpoint sources in sub watershed B46-09 of the Linville Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	424,415	1.11%	16,977	96%
Pasture[1]	31,625,300	82.66%	1,265,012	96%
Loafing Lots	4,852,020	12.68%	0	100%
Forest	6,908	0.02%	6,908	0%
Residential[2]	1,348,900	3.53%	13,489	99%
Total	38,257,543	100%	1,302,386	97%

[1] Includes Pastures 1, 2 and 3

[2] Includes Farmstead, Low and High Density Residential Loads

Table F-9b. Required annual reductions in direct nonpoint sources in sub watershed B46-09 of the Linville Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	55,585	73%	0	100%
Wildlife in stream	364	0%	18	95%
Straight pipes	19,824	26%	19,824	0%
Total	75,773	100%	19,842	74%

Table F-10a. Required annual reductions in nonpoint sources in sub watershed B46-10 of the Linville Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	10,024,993	10.76%	401,000	96%
Pasture[1]	76,017,000	81.62%	3,040,680	96%
Loafing Lots	5,635,800	6.05%	0	100%
Forest	19,751	0.02%	19,751	0%
Residential[2]	1,439,310	1.55%	14,393	99%
Total	93,136,854	100%	3,475,824	96%

[1] Includes Pastures 1, 2 and 3

[2] Includes Farmstead, Low and High Density Residential Loads

Table F-10b. Required annual reductions in direct nonpoint sources in sub watershed B46-10 of the Linville Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	60,357	86%	0	100%
Wildlife in stream	944	1%	47	95%
Straight pipes	8,838	13%	8,838	0%
Total	70,139	100%	8,885	87%

Table F-11a. Required annual reductions in nonpoint sources in sub watershed B46-11 of the Linville Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	7,544,250	6.57%	301,770	96%
Pasture[1]	99,959,700	87.10%	3,998,388	96%
Loafing Lots	5,191,200	4.52%	0	100%
Forest	19,599	0.02%	19,599	0%
Residential[2]	2,046,720	1.78%	20,467	99%
Total	114,761,469	100%	4,340,224	96%

[1] Includes Pastures 1, 2 and 3

[2] Includes Farmstead, Low and High Density Residential Loads

Table F-11b. Required annual reductions in direct nonpoint sources in sub watershed B46-11 of the Linville Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	77,664	86%	0	100%
Wildlife in stream	1,052	1%	53	95%
Straight pipes	11,641	13%	11,641	0%
Total	90,357	100%	11,694	87%

APPENDIX G

Simulated Stream Flow Chart for TMDL Allocation Period

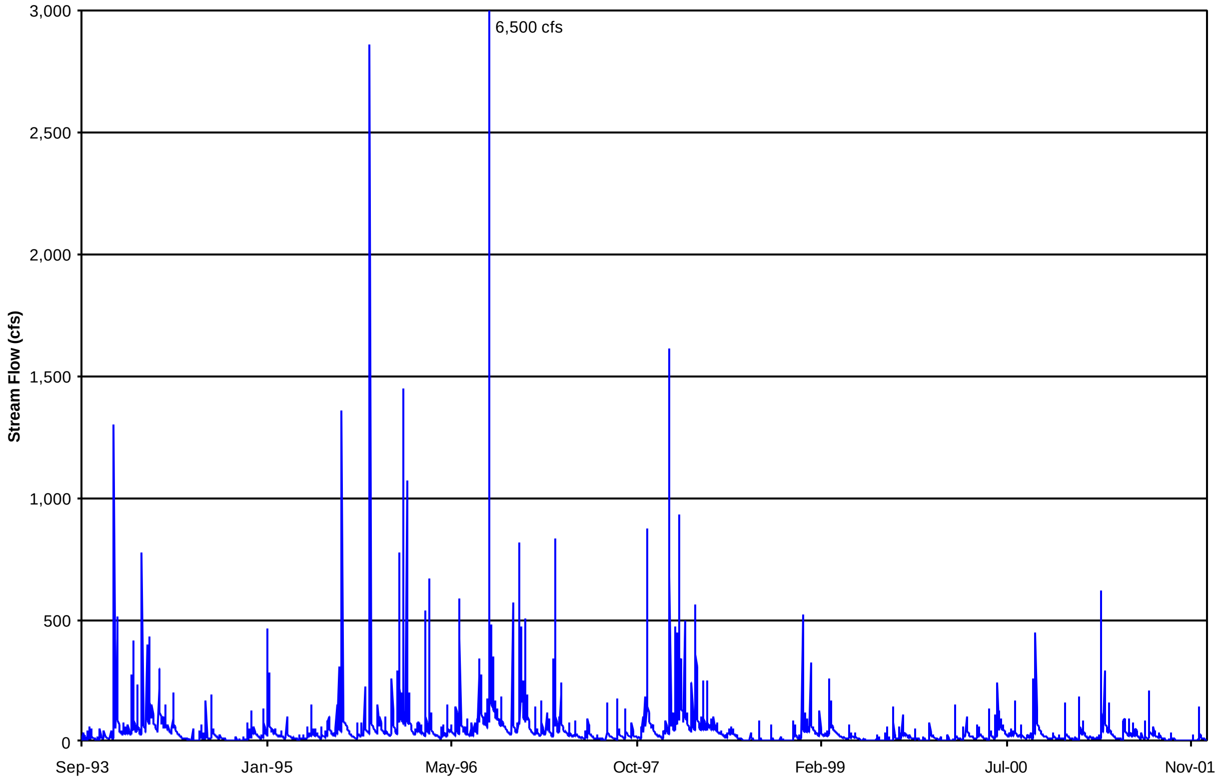

Figure G-1. Simulated Stream Flow for TMDL Allocation Period (September 1993 through December 2001)

APPENDIX H

Observed Fecal Coliform Concentrations and Antecedent Rainfall

Table H.1. Observed fecal coliform and *E. coli* concentrations and antecedent rainfall for Linville Creek

Station ID	Sampling Day	Fecal Coliform (cfu/100 ML)	*E. Coli* (cfu/100 mL)	Total Rainfall for Sampling Day and Preceding 5 days (inches)
1BLNV001.22	9/20/1993	1200	--	1.8
1BLNV001.22	10/20/1993	1000	--	0.8
1BLNV001.22	11/22/1993	100	--	0.5
1BLNV001.22	12/15/1993	500	--	0.3
1BLNV001.22	1/26/1994	3500	--	0.1
1BLNV001.22	2/15/1994	100	--	1.6
1BLNV001.22	3/16/1994	100	--	0
1BLNV001.22	4/12/1994	700	--	0.3
1BLNV001.22	4/16/1994	5400	--	1.2
1BLNV001.22	5/17/1994	1300	--	0
1BLNV001.22	6/30/1994	1800	--	0.9
1BLNV001.22	7/27/1994	1700	--	0.9
1BLNV001.22	8/17/1994	8000	--	2.7
1BLNV001.22	9/19/1994	600	--	0.2
1BLNV001.22	10/13/1994	100	--	0
1BLNV001.22	11/16/1994	1000	--	0.2
1BLNV001.22	12/20/1994	100	--	0.2
1BLNV001.22	1/17/1995	1400	--	1.6
1BLNV001.22	2/23/1995	100	--	0.5
1BLNV001.22	3/14/1995	230	--	0.1
1BLNV001.22	4/19/1995	5400	--	0.2
1BLNV001.22	5/18/1995	9200	--	2.38
1BLNV001.22	6/13/1995	1100	--	1.9
1BLNV001.22	7/13/1995	1300	--	0
1BLNV001.22	7/27/1995	5400	--	2.7
1BLNV001.22	8/17/1995	16000	--	0.6
1BLNV001.22	9/12/1995	16000	--	0.1
1BLNV001.22	10/17/1995	18	--	0.4
1BLNV001.22	11/15/1995	1300	--	1.3
1BLNV001.22	12/12/1995	68	--	0.2
1BLNV001.22	1/17/1996	130	--	0.4
1BLNV001.22	2/13/1996	140	--	0.1
1BLNV001.22	3/19/1996	230	--	1.5
1BLNV001.22	4/16/1996	5400	--	0.3
1BLNV001.22	5/14/1996	170	--	0.3
1BLNV001.22	6/18/1996	16000	--	1.3

Table H.1. Observed fecal coliform and *E. coli* concentrations and antecedent rainfall for Linville Creek (cont.)

1BLNV001.22	7/16/1996	16000	--	0.3
1BLNV001.22	8/13/1996	16000	--	3.8
1BLNV001.22	9/25/1996	700	--	0.4
1BLNV001.22	10/16/1996	2200	--	0
1BLNV001.22	11/21/1996	460	--	0.5
1BLNV001.22	12/18/1996	700	--	1.1
1BLNV001.22	1/29/1997	2200	--	0.8
1BLNV001.22	2/13/1997	20	--	0.8
1BLNV001.22	3/13/1997	78	--	0
1BLNV001.22	4/14/1997	790	--	0.7
1BLNV001.22	5/27/1997	1100	--	0.6
1BLNV001.22	6/18/1997	16000	--	0.3
1BLNV001.22	7/21/1997	330	--	0.8
1BLNV001.22	8/13/1997	16000	--	0
1BLNV001.22	9/15/1997	2200	--	1.4
1BLNV001.22	10/27/1997	45	--	1.5
1BLNV001.22	11/12/1997	5400	--	2.1
1BLNV001.22	12/3/1997	790	--	0
1BLNV001.22	1/7/1998	130	--	2.06
1BLNV001.22	2/10/1998	93	--	0.8
1BLNV001.22	3/19/1998	16000	--	1.5
1BLNV001.22	4/13/1998	330	--	1.2
1BLNV001.22	5/7/1998	1700	--	0.6
1BLNV001.22	6/18/1998	640	--	1.308
1BLNV001.22	7/21/1998	1300	--	0.235
1BLNV001.22	8/4/1998	330	--	0.06
1BLNV001.22	9/14/1998	3500	--	0
1BLNV001.22	10/6/1998	93	--	0.1
1BLNV001.22	11/4/1998	230	--	0.4
1BLNV001.22	12/10/1998	330	--	1.1
1BLNV001.22	1/5/1999	130	--	1.7
1BLNV001.22	2/17/1999	18	--	0
1BLNV001.22	3/18/1999	220	--	1.7
1BLNV001.22	4/20/1999	45	--	0.1
1BLNV001.22	5/13/1999	460	--	0.36
1BLNV001.22	6/2/1999	2400	--	0
1BLNV001.22	7/14/1999	100	--	0.216
1BLNV001.22	8/18/1999	100	--	0.732
1BLNV001.22	9/22/1999	2800	--	1.214
1BLNV001.22	10/20/1999	100	--	0.32
1BLNV001.22	11/30/1999	200	--	0.33
1BLNV001.22	12/14/1999	1000	--	0.954

Table H.1. Observed fecal coliform and *E. coli* concentrations and antecedent rainfall for Linville Creek (cont.)

1BLNV001.22	1/11/2000	220	10	0.3
1BLNV001.22	2/9/2000	25	10	0
1BLNV001.22	3/1/2000	25	10	0.08
1BLNV001.22	4/12/2000	25	30	0
1BLNV001.22	5/22/2000	2000	800	2.714
1BLNV001.22	6/1/2000	150	110	0.471
1BLNV001.22	7/20/2000	875	100	1.156
1BLNV001.22	8/10/2000	50	10	0.142
1BLNV001.22	9/19/2000	2000	800	1.8
1BLNV001.22	10/18/2000	25	10	0
1BLNV001.22	11/28/2000	75	10	0.366
1BLNV001.22	12/14/2000	50	30	0.710
1BLNV001.22	1/16/2001	400	30	0
1BLNV001.22	2/28/2001	100	40	0.3
1BLNV001.22	3/15/2001	200	370	0.4
1BLNV001.22	4/4/2001	420	330	0.3
1BLNV001.22	5/10/2001	200	170	0.2
1BLNV001.22	6/12/2001	380	380	0.2
1BLNV001.22	8/15/2001	650	420	1.512
1BLNV001.22	9/18/2001	600	470	0.1
1BLNV001.22	11/28/2001	25	10	0.553
1BLNV001.22	11/28/2001	25	10	0.553
1BLNV001.22	1/24/2002	25	10	0.180
1BLNV001.22	4/17/2002	180	80	0.570

APPENDIX I.

CAFOs in the Linville Creek Watershed

Table I.1 Permitted CAFOs in the Linville Creek Watershed

PermitNum	Integrator	Bird Type	Address	City	Comments
VPG260171	Pilgrim's Pride	Broiler	4911 Cromer Rd.	Harrisonburg	
VPG260081	George's	Broiler	5259 Cedar Run Trail	Broadway	
VPG260108	Tyson	Broiler	4173 Zion Church Road	Broadway	
VPG260123	Pilgrim's Pride	Broiler	5385 Sky Road	Harrisonburg	
VPG260173	Pilgrim's Pride	Broiler	5233 Greenmount Rd	Harrisonburg	
VPG260207	Pilgrim's Pride	Broiler	1285 Shank Drive	Harrisonburg	
VPG260576	Pilgrim's Pride	Broiler	6202 Greenmount Road	Harrisonburg	
VPG260644	Pilgrim's Pride	Broiler	5180 Trissels Road	Broadway	
VPG260634	George's	Broiler	4356 Greenmount Road	Harrisonburg	
VPG260214	Georges	Broiler	5776 Thompson Rd	Harrisonburg	
VPG260262	Georges	Broiler	13322 S. Sunset Drive	Broadway	
VPG260301	Tyson	Broiler	6717 Joseph Funk Lane	Singers Glen	
VPG260337	Georges	Broiler	4498 Greenmount Road	Harrisonburg	
VPG260410	Tyson	Broiler	7292 Turleytown Road	Singers Glen	
VPG260414	Georges	Broiler	7793 Turleytown Rd.	Singers Glen	
VPG260554	Tyson	Broiler	6404 Greenmount Road	Harrisonburg	
VPG260285	Tyson	Pullets/ Broiler	4040 Singers Glen Road	Harrisonburg	
VPG260632	Tysons	Broiler	13024 S. Sunset Drive	Broadway	
VPG260383	Cargill	Turkey	2977 Stone Hill Lane	Harrisonburg	
VPG260659	Pilgrim's Pride	Turkey	2634 Amberly Road	Harrisonburg	
VPG260654	Tyson	Broiler	2790 Fort Lynn Road	Harrisonburg	
VPG260122	Perdue	Broiler Breeder	2985 Kratzer Rd	Harrisonburg	
VPG260674	Pilgrim's Pride	Turkey	2719 Harpine Highway	Harrisonburg	
VPG260693	Cargill	Turkey	11486 Woodlands Church Rd	Broadway	
VPG260723	Pilgrim's Pride	Turkey	14592 South Sunset Drive	Broadway	
VPG260241	Pilgrim's Pride	Pullets	9670 Harpine Highway	Broadway	

Table I.1 Permitted CAFOs in the Linville Creek Watershed (continued).

VPG260096	Pilgrim's Pride	Broilers	9169 Indian Trail Road	Harrisonburg	
VPG260280	Cargill	Turkey	P. O. Box 169	Harrisonburg	
VPG260052	Tyson	Broiler	7254 Glen Hollow Road	Singers Glen	
VPG260002	Cargill	Turkey	2384 Potter John Lane	Dayton	Operation Address: 8019 Peter Driver Lane, Singers Glen VA
VPG260046	Tyson	Broiler	5964 Acker Lane	Linville	
VPG260048	Cargill	Turkey	5302 Green Hill Road	Linville	
VPG260172	George's	Broiler	6349 Harpine Hwy	Linville	
VPG260129	George's	Broiler	12595 Alta Vista Lane	Linville	
VPG260030	Pilgrim's Pride	Broiler	4485 John Deere Drive	Linville	
VPG260341	George's	Broiler	6187 Wengers Mill Road	Linville	
VPG260366	George's	Broiler	10284 Mount Zion Road	Linville	
VPG260647	Pilgrim's Pride	Broiler	7065 Wengers Mill Road	Linville	
VPG260426	Tyson	Broiler	10803 Wills Creek Road	Linville	
VPG260402	Cargill	Turkey	6559 Joes Creek Road	Linville	
VPG260518	Cargill	Turkey	5928 Kratzer Road	Linville	